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FORMATION OF DEBRIS FROM BUILDINGS AND THEIR CONTENTS BY BLAST AND FIRE EFFECTS OF NUCLEAR WEAPONS

Final Report
April 1966

Prepared for

DEPARTMENT OF THE ARMY
Office of the Secretary of the Army
Office of Civil Defense
OCD-PS-64-201
Work Unit 3312B

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FORMATION OF DEBRIS FROM BUILDINGS AND THEIR CONTENTS BY BLAST AND FIRE EFFECTS OF NUCLEAR WEAPONS

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by

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ABSTRACT

The prime objective of this phase of work is to augment the debris prediction model with additional information (debris charts, failure overpressures, contents-debris criteria, estimating procedures and data, etc.) to facilitate its application and increase its range of applicability.

To this end, new debris charts are presented which cover a more complete and detailed range of building types, along with a tabulation of failure overpressures for miscellaneous small structures (towers, poles, stacks, etc.). Criteria are developed for determination of debris from the contents of buildings, and furnished with these (for ease of use) are data relating the amount of material contained in buildings to building occupancy.

A description of the debris prediction model and its operation and a detailed worked example are presented illustrating the use of the model to determine debris contours over an entire city (Detroit) and debris profiles along a route through the city. In this example, debris depths before and after fire and the percentage contribution by building contents and structural components in each case are given. (Detailed descriptions of debris characteristics are beyond the scope of work covered by this report and therefore not included.)

Data (tables, charts, etc.) developed in this report and in earlier phases of this program have been assembled and are presented in Appendix A for ease of reference.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance and guidance furnished throughout the course of this work by Mr. Richard Bothun of Stanford Research Institute, Technical Monitor, and the valuable editorial services and guidance on publication requirements furnished by Mr. Allen Saltzman of URS.

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Section 1
INTRODUCTION

Prior knowledge of the amount, type, and distribution of structural and vegetational debris resulting from nuclear attacks on urban areas is essential to preplanning of transattack and postattack operations. Such debris could constitute a formidable impediment to all forms of overland transportation. Many activities and operations which require mobility in varying degrees (fire suppression, emergency mobilization, various countermeasures, supply lines, evacuation, rescue, reclamation, recovery, cleanup, etc.) both during and after the attack would be greatly affected by the amount of debris formed (by blast) or being formed (by fire or coupled blast and fire).

In many cases it would be necessary to remove debris before some of these operations could be executed at all. In such cases, preplanning of the operations would require not only predictions of the amount, type, and distribution of debris, but also predictions of the level of effort and the amount of equipment required to remove the debris. Scheduling and the approach taken to execute an operation could be vitally affected by logistic requirements for debris removal.

This study has been directed to the first of these problems — the development of techniques for predicting the amount, type, and distribution of debris — and this report summarizes activities carried out during its third phase.

In the first phase (Ref. 1), debris prediction charts were constructed which related overpressure from a 20-kt weapon to the amount of debris formed (by percentage of structure volume) from various rather broad categories of structure types. To illustrate the effects of weapon size, similar predictions made for a 20-Mt weapon were included on these charts.

During the next phase (Ref. 2) the effects of fire on debris formation were studied. Debris prediction charts reflecting the coupled effects of blast and fire were constructed for the same structure categories and weapon sizes previously considered.

In the last phase the following tasks were undertaken:

- The debris prediction model was extended to include some structures not previously considered, and was refined by adopting a more detailed set of categories for many of the structures already studied.
- Means for predicting the amount of debris formed by the contents of buildings were developed.
- A detailed description of the prediction model, its input requirements, and its operation was prepared, and — to illustrate the operation of this model — it was used to predict debris that would be created by the Five-City Study attack on Detroit, Michigan. In this example, general contours of debris depths for the entire city, and more detailed debris depths along routes through the city, were calculated.

As part of this last task, the utility of the debris prediction model was improved by devising simplified methods for estimating structural volumes and determining building areas.

Section 2
STRUCTURAL DEBRIS FROM BLAST AND FIRE

In the course of employing, for an analysis of debris depths in San Francisco (Ref. 2), the debris prediction charts developed in the first two phases of the study, large differences in debris production characteristics were noted. Further study indicated that many of these differences could be dealt with by adopting a finer set of structural categories and by including as specific types other structures commonly found in urban complexes. Accordingly, new charts have been prepared and, for certain small structures, simple overpressure failure criteria were established.

NEW DEBRIS CHARTS

The selection of building types for construction of these new charts was based not only on consideration of blast and fire vulnerability, debris production characteristics, and availability of data that would allow the general behavior of the building to be defined, but also on the availability of data that would permit buildings to be identified in urban complexes.

Data Analysis

The basic data for construction of these charts were obtained from bombing surveys, weapon tests, technical reports, and historical accounts of natural and man-made disasters. As before, the bombing surveys covering atomic attacks on Japanese cities (Refs. 3 through 8) provided valuable blast and fire damage data for numerous types of structures at various overpressures but had to be augmented with data from weapon tests, theoretical treatises, and miscellaneous other sources.

The bombing survey data were reviewed first to identify the various structure types and subtypes represented therein. Information on each type was then grouped for more thorough study. It was noticed at this time that mixed construction occurred frequently. For example, shear-wall and moment-

resisting frame systems were commonly found in the same building. These hybrids were evaluated and categorized on the basis of their dominant dynamic properties. If a reinforced concrete building contained a moment-resisting frame and light shear walls that would be blown out early in the failure history of the building, it was classified as a reinforced concrete frame building. If the shear walls were more substantial (and blast resistant), the building would behave as a shear-wall building and was so classified.

The bombing survey data were not complete. Sizable gaps existed for certain failure stages and in some cases, such as the substantial reinforced concrete shear-wall building, complete failure never did occur.

Damage analyses of buildings with similar components were used to fill gaps where component failure was in question. The weapons test data provided valuable information on various types of panels, walls, and sheathing. These data compare closely with the damage to similar elements observed in the Japanese buildings. Variations in construction practices, window aperture, and shielding account for the relatively minor observed spread.

Information based on theoretical considerations, such as that found in Ref. 9, was used for determination of collapse threshold overpressures for building types which did not sustain complete or partial failure of their main structural systems.

The terminal (100 percent debris) collapse overpressures for these buildings were then obtained by estimation of the amount of additional energy (in excess of that required to bring the building to the threshold of collapse) which the building would probably absorb in going from threshold of collapse to complete collapse and matching this (by calculations considering the dynamics of the systems) to the greater energy input from the impulse of higher overpressure blast waves.

All failure overpressures from these various data sources were adjusted or initially selected to reflect the effects of a nominal 20-kt weapon.

After determination of overpressures for the various stages of failure of each building type and various structural systems and components, the relative volumes of the components and failed portions were calculated as a percentage of the total volume of structural material in the building. This supplied the necessary information for construction of the basic 20-kt air-blast debris charts. By noting the percentage of combustible material in the various portions of the building and using the fire vulnerability information presented in the URS report 639-9 (Ref. 2) these curves were altered to reflect the coupled effects of air blast and fire.

Corresponding curves for the 20-Mt weapon size were obtained from these basic charts through utilization of structural dynamics procedures such as found in Refs. 10 and 11, which take into account the effect of variations in shock-wave characteristics (overpressure, dynamic pressure, positive-phase duration, impulse, etc.) on the dynamic response of the structure or its components. The response of structures and/or components to a specific blast wave depends on their dynamic properties, such as natural period of vibration, equivalent yield resistance, ultimate ductility ratios, etc. Typical values for these parameters are listed in Ref. 9.

Chart Construction and Description

Charts (Figs. 1 through 11) were constructed for the following building types:

1. Heavy reinforced concrete multistory shear-wall buildings with light interior panels
2. Heavy reinforced concrete multistory shear-wall buildings with masonry interior panels
3. Steel and reinforced concrete multistory frame buildings with earthquake design and light panels
4. Steel and reinforced concrete multistory frame buildings with earthquake design and masonry panels
5. Steel and reinforced concrete multistory frame buildings — non-earthquake design with light panels

6. Steel and reinforced concrete multistory frame buildings — non-earthquake design with masonry panels

7. Load-bearing masonry buildings with reinforcing or reinforced concrete spandrels

8. Light reinforced concrete shear-wall buildings with concrete roof and light interior panels

9. Light reinforced concrete shear-wall buildings with concrete roof and masonry interior panels

10. Light reinforced concrete shear-wall buildings with mill-type roof and light interior panels

11. Light reinforced concrete shear-wall buildings with mill-type roof and masonry interior panels

All these buildings vary considerably with respect to debris production when acted upon by blast and fire. In the following, a brief summary of special problems associated with the various types is presented.

Building Types 1 and 2 (Figs. 1 and 2) have identical basic structural systems but differ in the type of interior panels used. Changing the type of interior panel from light (typified by stud, lath and plaster or wall board, and by pressed metal construction) to heavy (masonry) increases the volume of structural material in the building by over 70 percent (see Table A-3), which would in turn increase the amount of debris produced by destruction of the building. The percentage increase in debris production would be greater if just the panels were destroyed.

When fire effects are present, the light panels, being more vulnerable to fire, would fail and produce debris at distances from the burst where overpressures alone would be too low to cause panel failure. Note on Fig. 1 that significant coupled blast and fire effects begin at very low overpressure levels.

An additional curve for a 20-Mt weapon acting on these buildings was drawn to illustrate the effect of variations in building height. The fact that the taller buildings require smaller overpressures for equivalent destruction than the shorter buildings is due to the longer periods of vibration of the former, making them more sensitive to the longer positive-phase duration of blast load associated with large weapon yields.

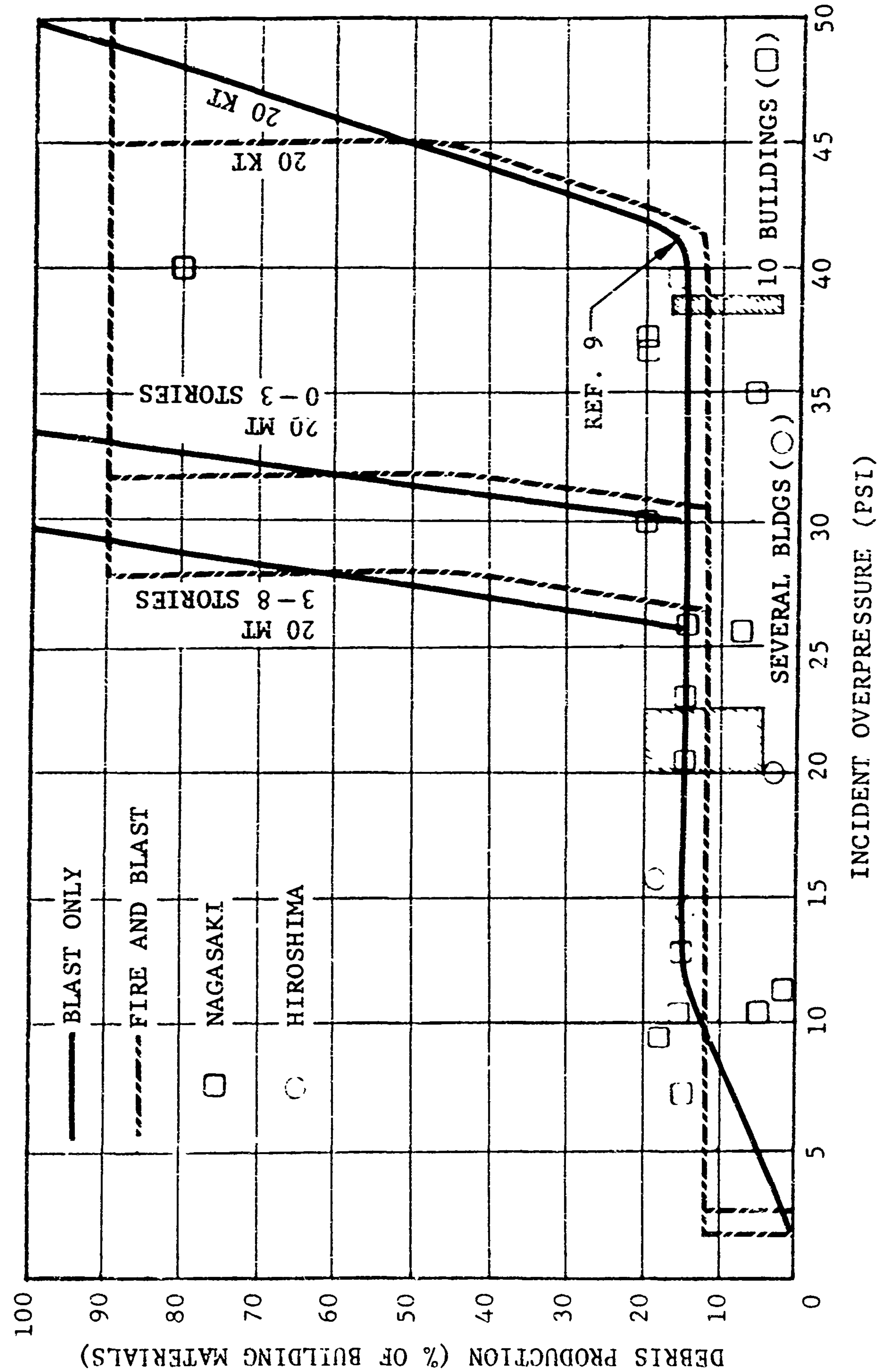

Fig. 1. Coupled Fire and Blast Percent Debris vs Overpressure — Heavy Reinforced Concrete Multistory Shear-Wall Buildings With Light Interior Panels

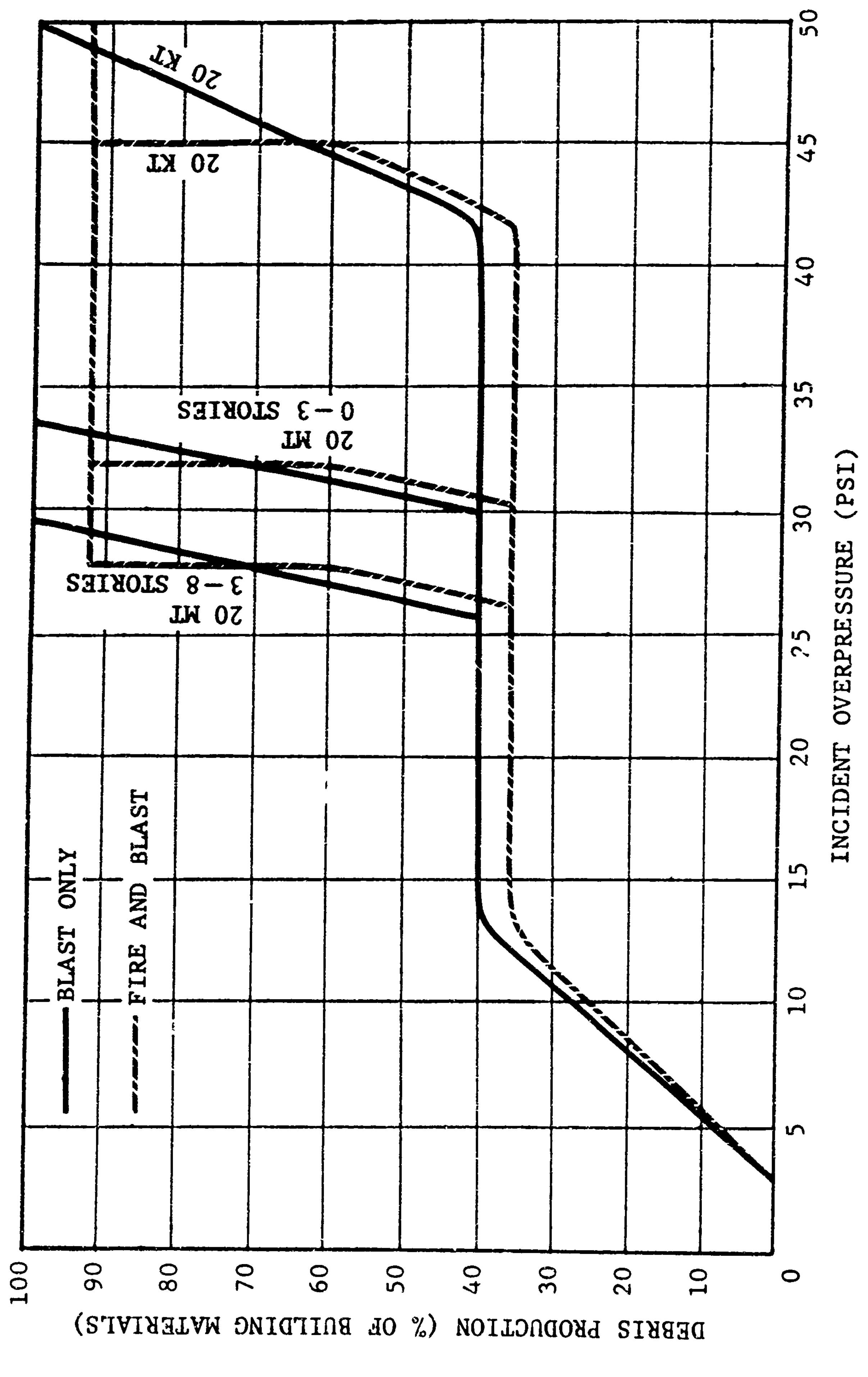

Fig. 2. Coupled Fire and Blast Percent Debris vs Overpressure — Heavy Reinforced Concrete Multistory Shear-Wall Buildings With Masonry Interior Panels

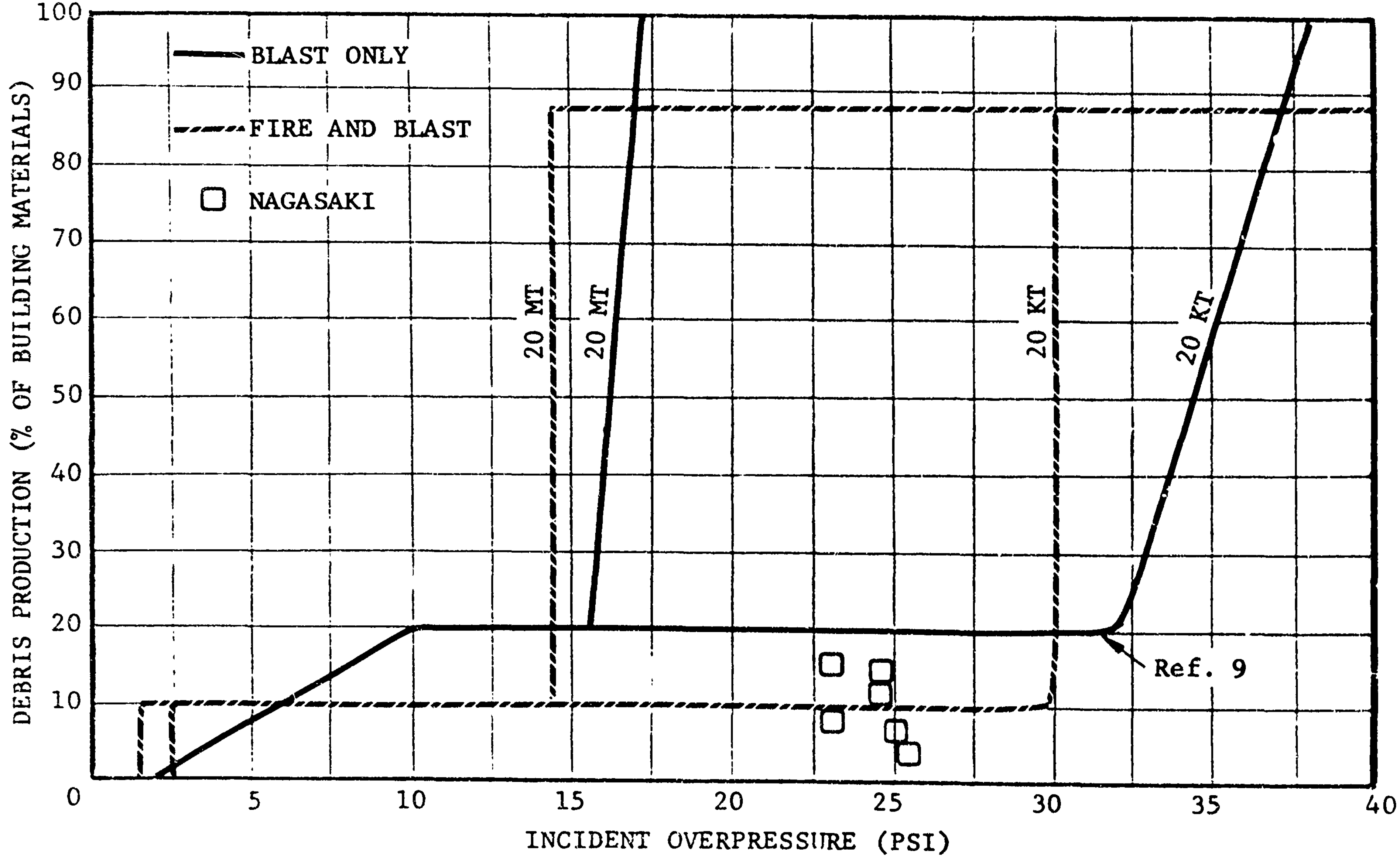

Fig. 3. Coupled Fire and Blast Percent Debris vs Overpressure — Multistory Steel and Reinforced Concrete Frame Buildings With Earthquake Design and Light Panels

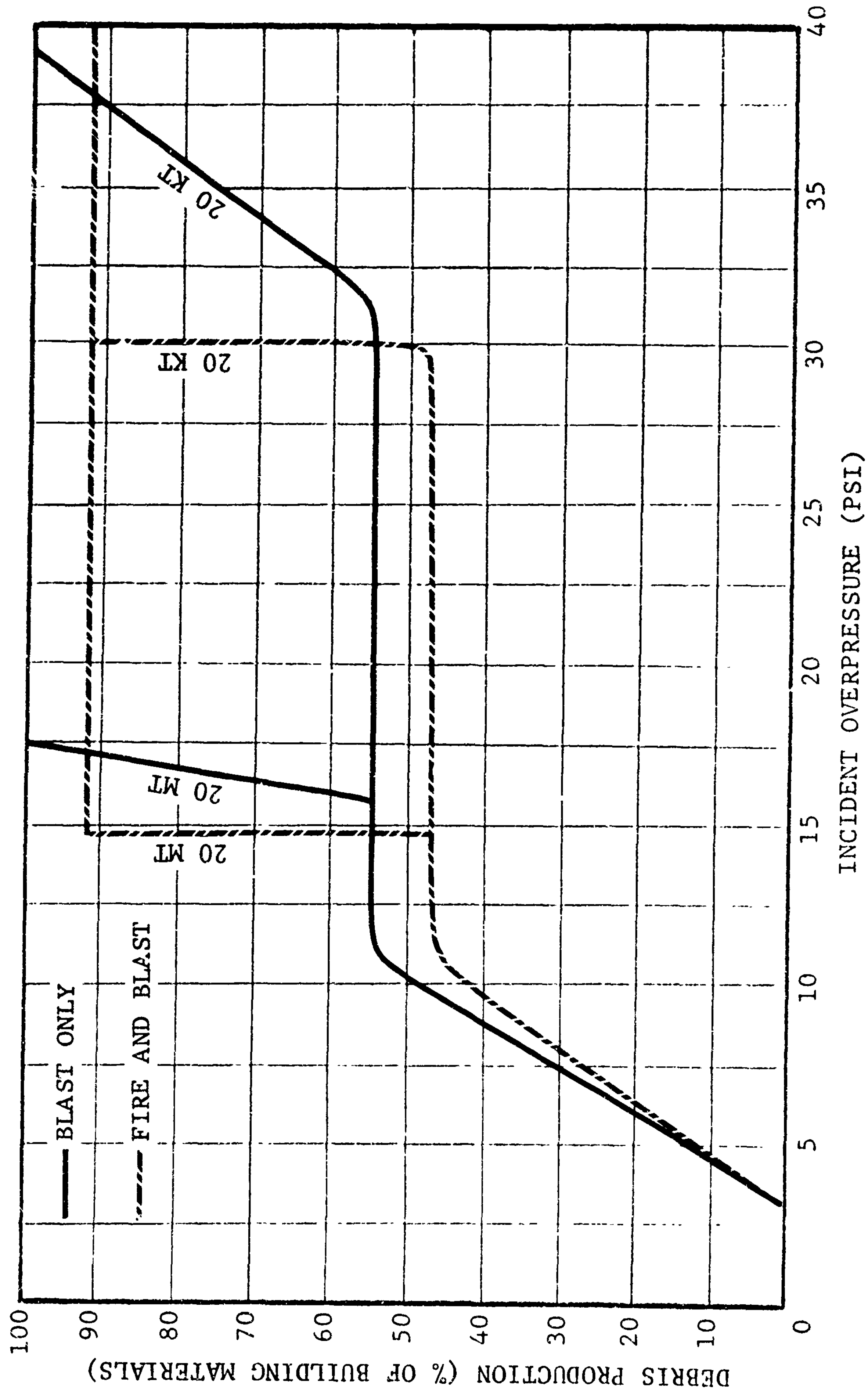

Fig. 4. Coupled Fire and Blast Percent Debris vs Overpressure — Multistory Steel and Reinforced Concrete Frame Buildings With Earthquake Design and Masonry Panels

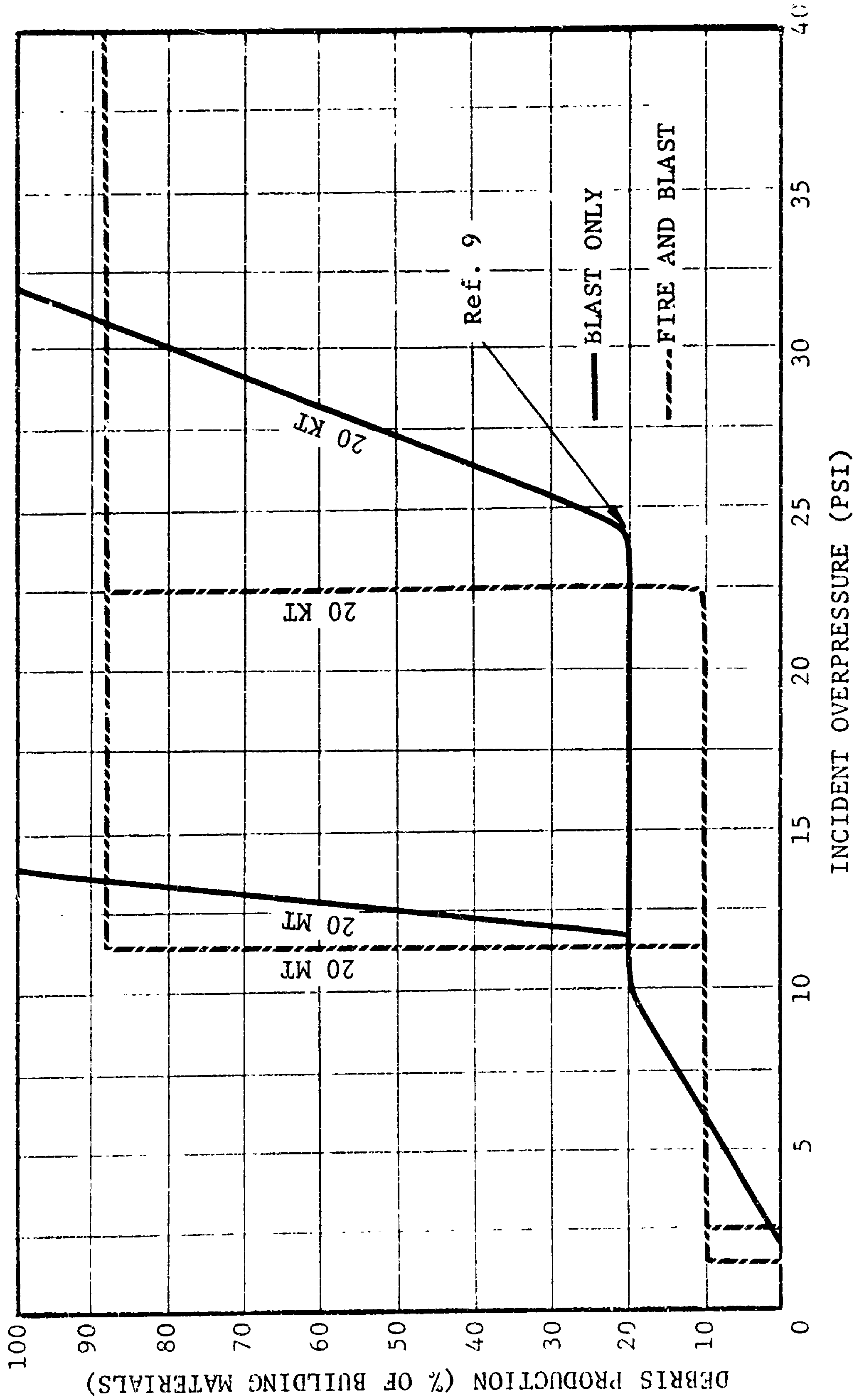

Fig. 5. Coupled Fire and Blast Percent Debris vs Overpressure – Multistory Steel and Reinforced Concrete Frame Buildings – Non-earthquake Design With Light Panels

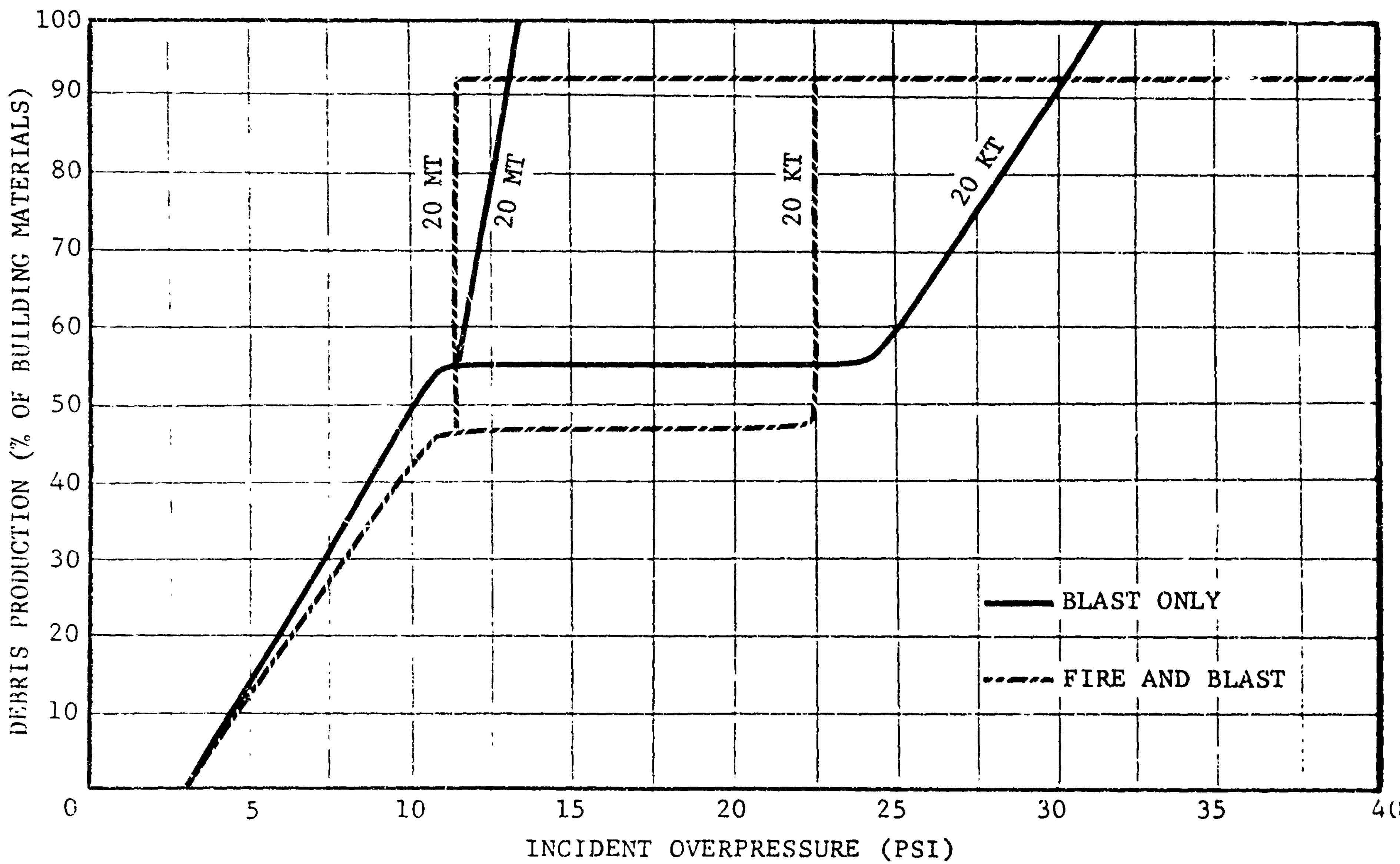

Fig. 6. Coupled Fire and Blast Percent Debris vs Overpressure — Multistory Steel and Reinforced Concrete Frame Buildings — Non-earthquake Design With Masonry Panels

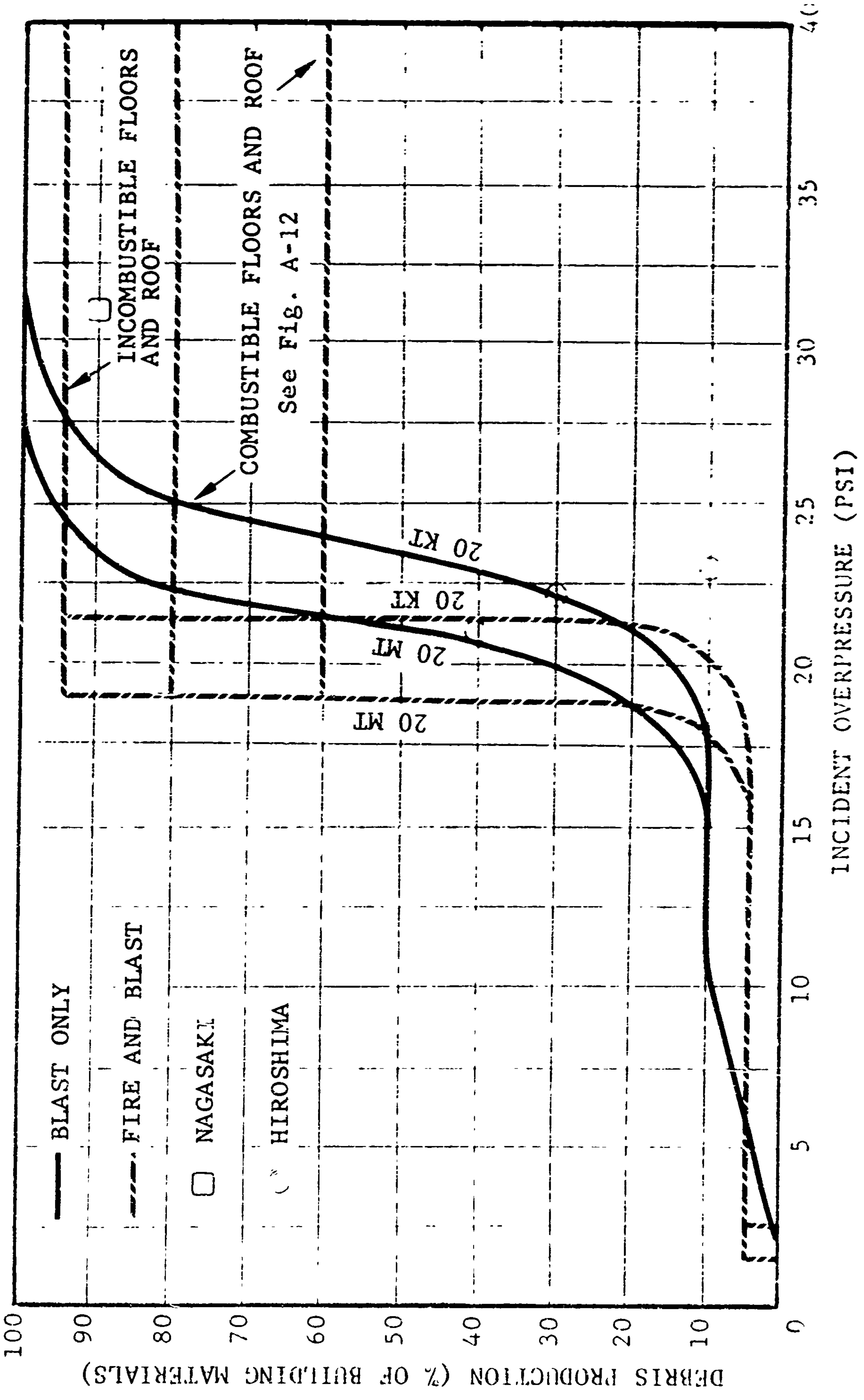

Fig. 7. Coupled Fire and Blast Percent Debris vs Overpressure — Load-Bearing Masonry Building With Reinforcing or Reinforced Concrete Spandrels

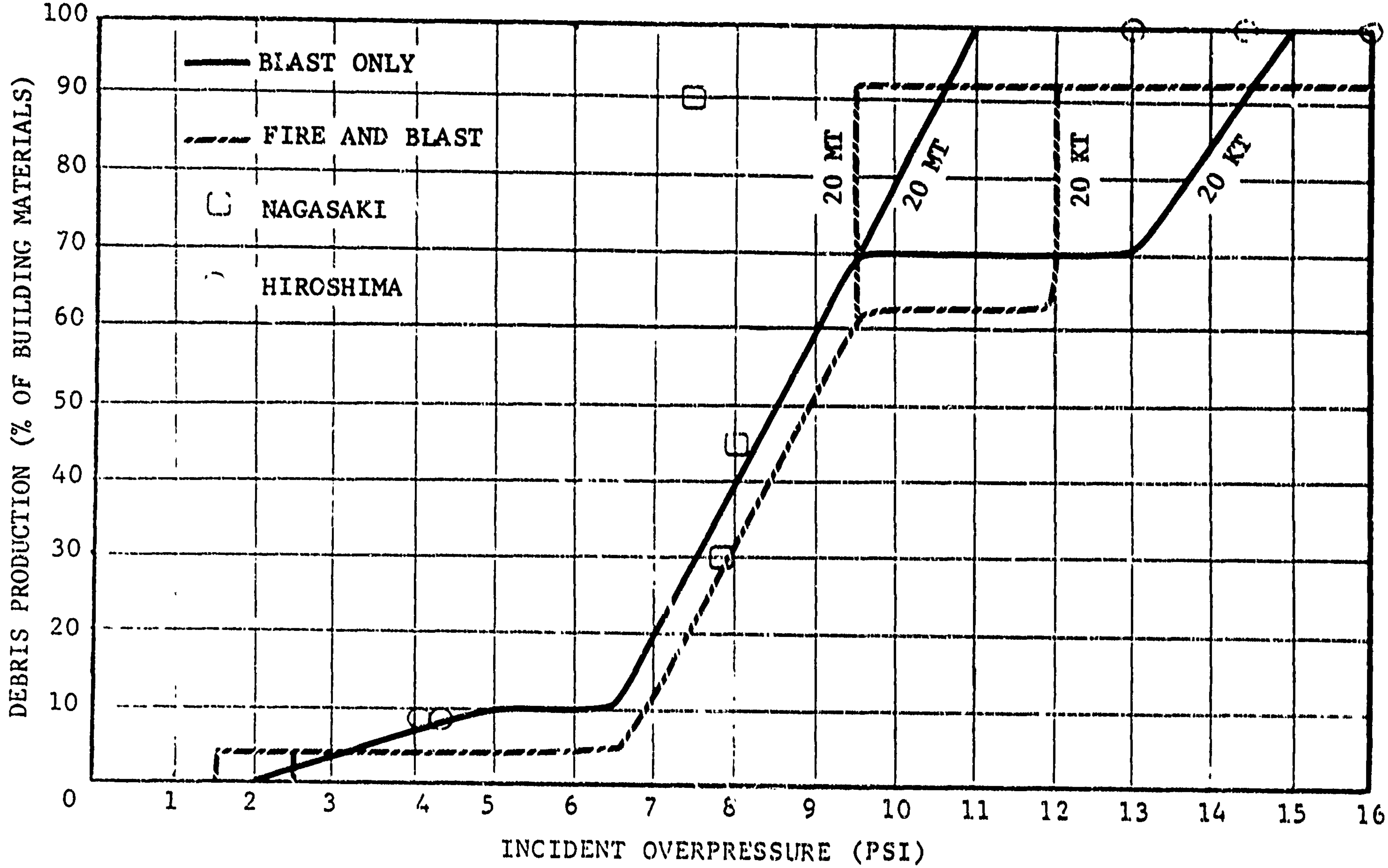

Fig. 8. Coupled Fire and Blast Percent Debris vs Overpressure — Light Reinforced Concrete Shear-Wall Buildings With Concrete Roof and Light Interior Panels

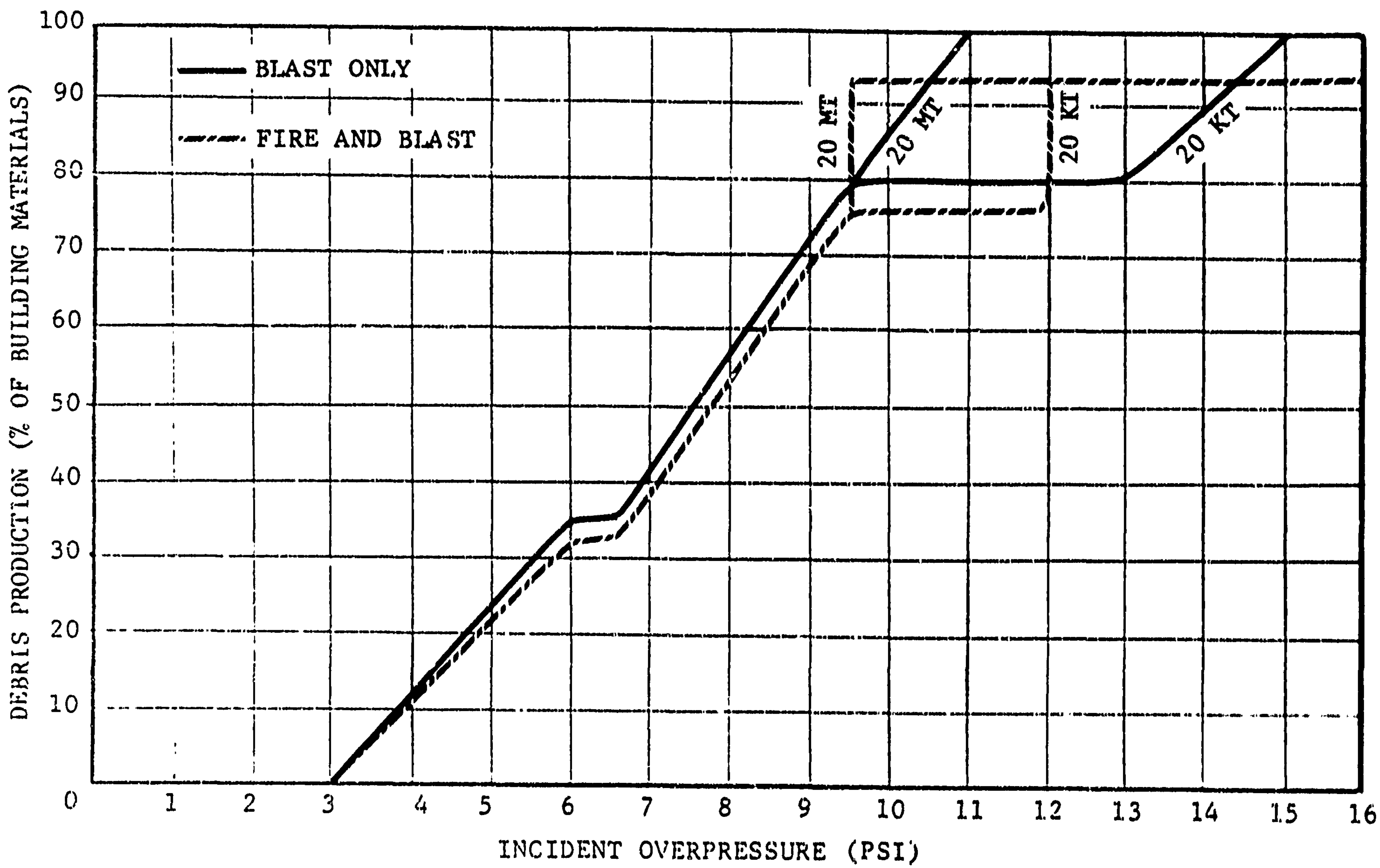

Fig. 9. Coupled Fire and Blast Percent Debris vs Overpressure — Light Reinforced Concrete Shear-Wall Buildings With Concrete Roof and Masonry Interior Panels

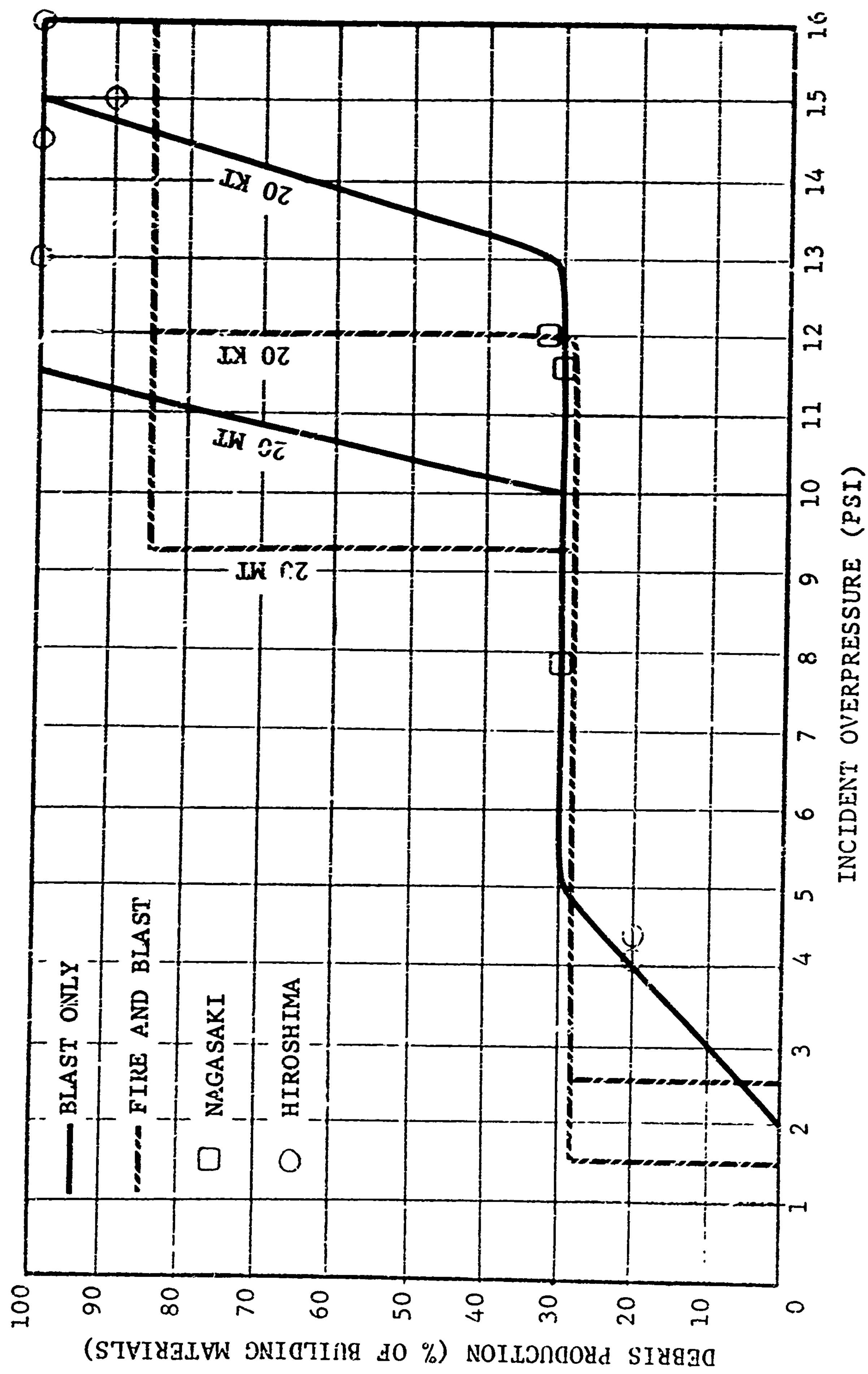

Fig. 10. Coupled Fire and Blast Percent Debris vs Overpressure — Light Reinforced Concrete Shear-Wall Buildings With Mill-Type Roof and Light Interior Panels

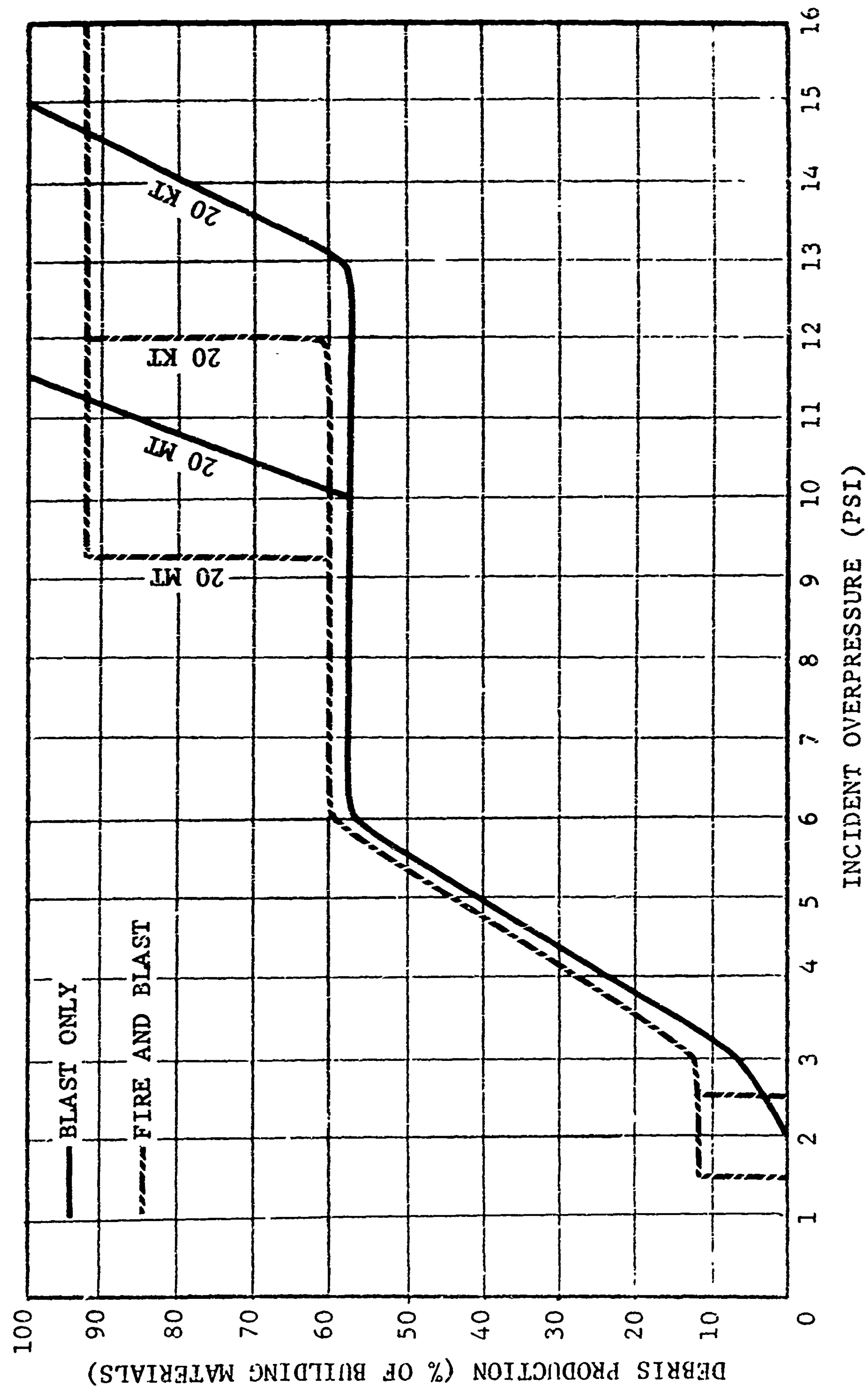

Fig. 11. Coupled Fire and Blast Percent Debris vs Overpressure — Light Reinforced Concrete Shear-Wall Buildings With Mill-Type Roof and Masonry Interior Panels

Building Types 3 and 4 also contain similar structural systems but differ again primarily by type of interior panels. These types were treated in the same manner as Types 1 and 2 in this respect. Note that the debris charts for these building types (Figs. 3 and 4) exhibit greater shifts in overpressure for equivalent destruction (20-kt vs 20-Mt curves) than those for Types 1 and 2. This is due to the longer natural periods of vibration and the greater ductility ratios inherent in this type of building.

The overpressures defining the knee at the start of the terminal limb of the air-blast debris curves for Types 1 through 4 were obtained from Ref. 9, since complete failure of these buildings did not occur in Hiroshima or Nagasaki and no building of this type has been tested to failure.

Virtually no damage data were available for Types 5 and 6 since they were not included in weapons tests and did not exist in Hiroshima and Nagasaki. This building is common in areas of low seismic activity (the greater part of the United States). Consequently, debris charts (Figs. 5 and 6) were synthesized by using information from Ref. 9 and failure analysis of other structures with similar typical components and comparable dynamic characteristics.*

Building Type 7 (see debris chart, Fig. 7) was established as a separate category as a result of apparent inconsistencies found in bombing survey data. In reviewing these data, some brick masonry buildings were noted to have withstood appreciably greater overpressures (with minor amounts of damage) than those that completely destroyed other structures, apparently of the same type. The inconsistency was of sufficient magnitude to merit further investigation.

The structures exhibiting this more substantial characteristic were studied in more detail. The thickness of walls, sizes of members and general

* An analytical investigation presently in progress (under the cognizance of Dr. R. Condit of SRI — Project No. SRI 4949-010) may yield further information of these buildings.

weight class of these structures were about the same as those that failed at lower overpressures. The clue to their strength was found when some reinforcing steel in rubble from one of these buildings was noticed. A further detailed check (knowing what to look for) revealed that all these stronger buildings were reinforced. Although the amount of reinforcing was small, it was strategically placed and thereby increased the strength and blast resistivity of the buildings considerably (compare Fig. 7 to Fig. A-4). The shells of those buildings, left after being gutted by fire, were also more stable, akin to the reinforced concrete shear-wall building.

The response of these buildings is similar to that of heavy reinforced concrete shear-wall buildings when subjected to blast loading. Their shorter period of vibration makes them a bit more diffraction-phase sensitive, and weaker structural materials and lighter reinforcing make them less blast-resistant.

Building Types 8 through 11 contain similar lateral resistance elements (light reinforced concrete shear walls) but differ in roof type and again in the type of interior panels. The variations in panels were handled in the same fashion as the previously described buildings.

A further division had to be created, however, to describe roof type variations. The mill-type roof is usually sheathed with corrugated iron or asbestos sheathing which fails at much lower overpressures (less than 3 psi) than those for the deck portion of the concrete roofs (6 to 10 psi), and contains a much smaller volume of material. The mill-type roof is usually not fireproofed and consequently is much more vulnerable to fire. These effects account for the major differences in the debris charts for these buildings (Figs. 8 through 11).

The charts for Types 1 through 11 are also included in Appendix A (Figs. A-5 through A-16) along with charts developed in earlier phases of this study for other types of buildings (Figs. A-1 through A-4).

Small Structure Failure Overpressure

In reviewing the damage information for construction of the new debris charts, note was also made of overpressures at which miscellaneous, small,

primarily drag-sensitive structures failed. These structures, although generally insignificant, may figure prominently in some specific analyses. Consequently, failure overpressures for these structures were assembled and tabulated for the 20-kt and 20-Mt weapons and are presented in Table 1.

Table 1

FAILURE OVERPRESSURES FOR SMALL DRAG-SENSITIVE STRUCTURES AND ELEMENTS (20-kt and 20-Mt weapons)

Description	Overpressure at Failure (psi)	
	20 kt	20 Mt
Transmission Poles		
Radial Lines	8	3.8 (Ref. 12)
Transverse Lines	9	4.5 (Ref. 12)
Transmission Towers	10	5
Average Forest	8	3.8 (Ref. 12)
Stacks		
Reinforced Concrete:		
Over 4 ft diameter	25	11
4 ft and smaller diameter	15	7
Steel	5.5	2.6
Brick	5	4.5 (estimated)

Section 3
BUILDING CONTENTS

The contents of buildings, as well as structural parts, can contribute significantly to the amount of debris produced. Quantification of the contribution of building contents to the total debris problem requires detailed knowledge of the amount of and character of these contents.

Both the amount and character of debris from building contents will depend to a great extent on the use or occupancy of the building. The basic design of the structure also depends on the projected use or occupancy; consequently, information developed to establish design criteria has proved very useful. Detailed information has been found (Refs. 13 through 18) on both the total weight of contents per square foot and the amount of this material that is combustible. Information on combustible contents has also been collected and presented in Refs. 15 through 17, which, in general, ignore incombustible contents.

Data found in National Bureau of Standard Reports BMS92, 133, and 149 proved to be most useful for general occupancy coverage. Data presented in these reports were obtained by actually weighing and categorizing the contents of several buildings and converting these data to pounds per square foot for various building area uses. The data were quite detailed, giving weights and areas for each area usage encountered (such as various weights in sections of a department store) and for each floor in multistory buildings.

For adaptation to the debris model, the data were grouped into occupancy classifications which can be read directly from Sanborn maps. Weighted averages were used to find the average load per square foot for each occupancy. These are tabulated in Table 2. Estimated values for packed density (no voids between articles, although voids may be contained within the confines of an article, such as the storage space in a refrigerator) were used to obtain volume coefficients K. The volume of building contents V (in cubic feet), is then found by applying the formula:

$$V = KA_pN$$

Table 2

BUILDING CONTENTS LOADS AND VOLUME FACTORS

Occupancy	PSF Combustible	PSF Total	Volume Factor K ($V = KA_pN$)* Total	After Fire
Apts. and Residential	3.5	5	0.625	0.02
Auditoriums and Churches	1	1.5	0.25	0.007
Garage				
Storage	1	15	0.75	0.30
Repair	1	11	0.55	0.20
Gymnasium	0.3	0.5	0.09	0.003
Hospitals	1.2	3	0.375	0.03
Hotels	4	5	0.625	0.013
Libraries	24	26	0.75	0.027
Manufacturing				
Comb. Mdse. fabrics, furniture	13.5	18	1.8	0.07
Incombustible	1	11	0.55	0.20
Offices	7	12	1.2	0.10
Printing Plant				
Newspaper	10	23	0.9	0.20
Books	50	60	1.7	0.13
Schools	9.5	11	1.6	0.02
Storage				
Gen. Mdse.	14	35	6	0.3
Special		**		
Stores				
Retail Dept.	7.5	12	2	0.10
Wholesale	10	16	2.7	0.12
Restaurant	2	3.5	0.6	0.02

* V = Volume in cubic feet
A_p = Plan area in square feet
N = Number of stories

** 25 percent of design load.

where A_p is the plan area in square feet* and N is the number of stories in the building.

The amount and type of materials stored in warehouses, particularly special-purpose warhouses, can vary over a considerable range. For these it was found that the contents usually amounted to about 25 percent** of the design load for the warehouse. This accounts for aisle space and fluctuations in the amount of material stored.

DEBRIS FROM BUILDING CONTENTS

Building contents become debris when, by action of blast and/or fire, their usefulness is destroyed or their remains constitute a cleanup problem instead of a part of a resource. With this definition in mind, the following criteria were adopted:

Action	Contents Considered As Debris
Contents ejected by blast	yes
Contents destroyed by fire	yes
Contents destroyed by blast	yes
Building destroyed by blast or fire	yes
Contents displaced by blast but not destroyed or ejected	no

To apply these criteria, the state of the contents — whether displaced, ejected, burned, or destroyed by blast — must be known. Stipulation of building destruction and the presence of fire effects is not difficult. Determining whether the articles have been merely displaced by blast or destroyed and/or ejected becomes much more difficult. Trajectory studies are presently in progress (by others). These have not yet considered the ejection problem, are at present in an embryonic stage with respect to this problem, and consequently not useful for this problem. Also, no good

* It is usually most advantageous to calculate contents volumes in cubic ft since building dimensions are usually given in ft (on Sanborn maps). This avoids combersome conversions to other units.

** This figure is also commonly specified in building codes (Ref. 18) for use in obtaining forces from lateral seismic accelerations.

source of information on blast damage to contents has been uncovered in the data search. Therefore, techniques for prediction of damage to and ejection of building contents were based on logical extensions of related techniques.

In most occupancies, the durability of the typical contents is not too different from that of the internal panels with respect to blast vulnerability. (An exception to this is permanently installed heavy industrial machinery or equipment.) If the blast intensity were sufficient to destroy the panels, in all likelihood the contents of the building would also suffer.

In this same vein, if portions of the blast-formed debris from the interior panels were to be ejected from the building, it is logical to assume that part of the building contents would likewise be ejected. If all the debris from the interior panels were to be ejected from the building, the major part of the building contents would undoubtedly also be ejected.

In previous phases of this study, criteria were developed for determining whether interior panels would fail or not. These criteria, suitably modified, form the basis for estimating whether building contents would become debris (with due regard for obvious cases where these rules would not apply). Application of these criteria is made quite convenient by recognizing that the initial rising limb of most of the debris charts is essentially the result of panel failure The beginning of the first plateau generally represents the point at which panel failure would be complete and -- in accord with the relationship between panel and building content failure just described — it would also represent the point at which all the building contents become debris. For lower overpressures, the percent of contents converted to debris can be estimated by linear interpolation.

Section 4
MODEL DESCRIPTION

The debris prediction model is designed to provide a means for predicting the amount of debris that would be produced by blast and fire effects of a nuclear attack on an urban area. As such, the output can be in the form of general debris depth contours covering the entire city, or more accurate debris depths in specific locations or along routes into or through the city. The contours can be used to gain a general picture of the debris problem over the entire city and, in addition, can be invaluable in solving specific, more detailed problems, such as selection of least obstructed routes.

The model does not include means for determining fire spread, but it can be integrated with a fire-spread model for determination of the limits of fire-affected areas. Should such fire-spread information not be available, the debris estimates can be bracketed by arbitrarily including and excluding fire effects in specific portions of the city.

To facilitate the use of the model, input information required is briefly described in this section of the report, and the sources through which this information can be obtained are tabulated and discussed. The section also includes a step-by-step outline of the model's operation and indication of how each step is to be carried out.

INPUT DATA

Input data required for operation of the model include weapon size and location and city layout, with detailed information on buildings and structures within the city. In addition to these, meteorological data are required for prediction of fire effects. The meteorological data can be obtained from weather records and the attack information estimated or synthesized. The city data (which comprise the major portion of input data) can be obtained from the following sources:*

* Illustrations of many of these are included in the example problem (Section 5).

1. Quadrangle maps
2. City street maps
3. Land-use maps
4. Buying-power maps
5. Aerial mosaics
6. Sanborn maps
7. On-site reconnaissance
8. Miscellaneous: panoramic photos, zoning maps, building regulations, etc.

General topographic information about the city, its prominent features and its surrounding area, can be obtained from quadrangle maps. These maps are also useful in locating the weapon burst point since they are accurate as to scale and detail and are referenced in both Geodetic and Universal Transverse Mercator Coordinate Systems.

The street maps provide detailed information on roads, streets, and general layout of the city.

A more detailed concept of the composition of the city can be obtained from land-use and buying-power maps. The land-use maps identify residential, industrial, and commercial districts, and the buying-power maps serve to identify and bound the major subsections of residential areas. These maps are useful in the interpretation of aerial photography from which current integrated information on development and extent of the various areas as well as ground cover and vegetation can be obtained. They are also useful to the planning of on-site reconnaissance, should aerial photography prove inadequate or unavailable.

Detailed knowledge of the sectional composition of the city will enable the efficient selection of Sanborn maps for sample areas in homogeneous sections and for adequate coverage in areas of changing built-upness or in heterogeneous areas. These Sanborn maps are as yet the best source of detailed building information, which is essential to the operation of the debris model.

Should information from some of these sources not be available, the model can still be used, but with a lesser degree of relative accuracy and/or efficiency.

OPERATION

After determination of the objectives of the investigation and assembly of the input data required to satisfy those objectives, the debris model is then ready for operation. This involves the following procedure:

1. Determine overpressure vs distance (from size and height of burst of weapon) (see Fig. 15).

2. Determine occupancy, type, and size of building (usually from Sanborn maps (see Fig. B-2).

3. Determine overpressure at building's location.

4. Enter proper curve (for type of building and size of weapon) with overpressure to obtain percentage of structure converted to debris by

   a. Blast only

   b. Blast and fire (if in burned area)

   (see Figs. A-1 through A-16).

5. Refer to debris overpressure criteria for contents to determine percent of contents of the building converted to debris (Section 3).

6. Calculate total structural material volume (see Table A-3).

7. Calculate volume of contents (see Table A-2).

8. Apply percentage figures to structural and contents volumes to determine volume of debris from building.

9. Distribute debris.*

10. Repeat for next building.

11. Sum up all contributions and apply void ratio** to obtain debris depths at specific locations.

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* At present, simplified procedures are used for distribution debris. These can be refined and improved upon when more trajectory data are made available.

** Since the void ratios (volume of voids divided by the volume of solid material) for most materials are commonly close to unity, it is customary to assign this value in absence of a measured value.

These debris depths may be used for investigation of specific areas, to plot debris profiles along routes through the city, or as control points for construction of debris depth contours, etc.

Section 5

EXAMPLE OF APPLICATION OF DEBRIS MODEL

CITY SELECTION

It is stipulated by the Office of Civil Defense that in any application phase of research under its sponsorship, one of the cities (San Jose, Albuquerque, New Orleans, Providence, and Detroit) covered by its Five-City Study should be used. Consequently, each of these cities and its associated attack conditions were investigated with respect to debris production in order to select the city (Detroit) best suited for illustration of the application of the debris prediction model. With the aid of street maps, quadrangle sheets, and general descriptive data, each of the five cities was studied to determine the general level of damage and potential debris problems resulting from the attacks specified in the Five-City Study.

The results of this preliminary generalized investigation are summarized as follows:

San Jose

The 5-Mt burst at 14,000 ft over Moffett Field would impart an overpressure of about 2 psi on downtown San Jose. This overpressure is insufficient to produce appreciable amounts of debris. This light-to-moderate damage area would, however, be vulnerable to fire, which could produce considerable debris in the central business district, the major part of which is clustered along First Street for a distance of about 3 miles.

Albuquerque

The 2-psi isobar from the 5-Mt weapon detonated 14,000 ft above the southern lip of Tijeras Canyon (on the southeast edge of town) completely envelops this city. Although the major portion of this city would suffer complete destruction from this attack, debris depths would be relatively shallow since the city contains few tall buildings and is characterized by a liberal spacing between buildings, wide streets, and very little debris-producing vegetation. Subsequent fires, which are highly probably, would serve to further alleviate debris problems by consuming combustible portions of that formed by air blast.

Providence

The 1-Mt surface burst detonated about 17 miles due south of Providence (US Naval Const. Bn., Davisville) will produce overpressures

of less than 1 psi over this city. At this overpressure level air blast damage would be very light (broken windows, etc.). Consequently, negligible amounts of debris would be produced from air blast within the city. Appreciable debris from fire effects is also unlikely, since Providence is out of range for primary ignitions and there is good likelihood that firefighting and fire countermeasures will diminish damage from other fires. Fires and blast-formed debris from vegetation, however, might constitute a significant problem in areas closer to ground zero.

New Orleans

The 4-psi isobar from the 10-Mt surface burst detonated near the north corner of the Customs House (located in the French Quarter) will envelop the entire city of New Orleans. Since the larger and more substantial structures in this city are located in the high-overpressure area, nearly complete destruction by air blast is predicted. Consequently, appreciable amounts of debris would be produced. Fire, too, would be prevalent, but prediction of its ultimate effects is somewhat complicated by the fact that the breaching of the dikes and levees along the Mississippi River would produce flooding of this low-lying area.* This would inhibit fire consumption of combustible debris deposited over the flooded area and would also redistribute bouyant portions in an as yet unpredictable fashion.

Detroit

The 5-Mt surface burst near the intersection of Casper and McGraw is sufficient to cause wide-spread damage to the city of Detroit, varying from heavy damage on the west side to light damage in the eastern portions. The downtown section will receive from 5 to 10 psi, which will cause only partial destruction to numerous substantial multi-story structures. It can be expected that ejected building contents will constitute the major portions of the debris in this section. Fire effects will be present but probably will not be the dominant agent of destruction, considering the general sparsity of extreme fire-vulnerable areas within this city.

San Jose and Providence were not selected for this study (but may be considered in a later study) because the low overpressures to which they would be subjected would produce very little air-blast-formed debris.

Although Albuquerque would suffer nearly complete destruction, it was not used because its debris problem was not serious, a result of the absence of tall buildings and a small building-to-land-area ratio.

* Weapon is located such that the lip of the crater would extend well into the river.

New Orleans would contain appreciable debris in wide variety, but was eliminated because of the complications arising from flooding and possible liquefaction (turning to mud and flowing) of surface strata. Methods for handling these problems are at present nonexistent and should be the subject of future research.

Detroit was selected as the most desirable city to be used in the application phase because it contains many types of structures and because the attack specified would produce a broad range of damage.

WORK PLAN

The work plan for the application phase was formulated as outlined below:

Attack

City - Detroit
Weapon - 5-Mt surface burst
Location - 42°20'07"N, 83°08'28"W

Work Objectives

Construct general debris contours for city.
Plot debris depth along selected route through city.

Approach

Debris Contours

From general information (land-use and street maps and aerial photos) select debris depth control points.

Determine cell size for area representation at each point.

Obtain Sanborn maps for selected points.

Calculate depths of debris at control points — one for blast only and one for blast and fire.

Construct two sets of contours — blast only and blast and fire — and note contents contribution at selected points.

Debris Depths Along Route

Select route.

Obtain Sanborn maps for route.

Calculate debris depths along route — blast only and blast and fire. Include building contents.

Plot debris depth vs distance along route.

DATA ACQUISITION

The layout of the city was studied in detail (with the aid of street, quadrangle, and land-use maps) to determine its general makeup. This effort was essential to efficient planning of data points for construction of debris contours and selection of a feasible route through the city.

Due to lack of aerial photography during this phase, an on-site reconnaissance of the city had to substitute for verification of the feasibility of the preselected route. This enabled efficient selection of data points for both route and contour portions and provided an excellent opportunity to make cell-size determination observations.

Sanborn maps were requisitioned for points of change along the selected route and for contour control points, representative of nearly homogeneous sections, throughout the city. The nearly homogeneous residential sections were found to be, in general, bounded by local industrial or commerical strips. (See land-use map, Fig. 12.)

The downtown commercial section was found to be characterized by a rather steep gradient of built-upness, with maximum occuring in the vicinity of Grand Circus Park (a core-type city) (see Fig. 13). This area could not be typified by any one block or section. Consequently, several maps had to be obtained to adequately define this relatively small section (approximately 1 square mile).

To facilitate determination of areal limits of typical sections (essential to construction of debris contours), a set of aerial photographs

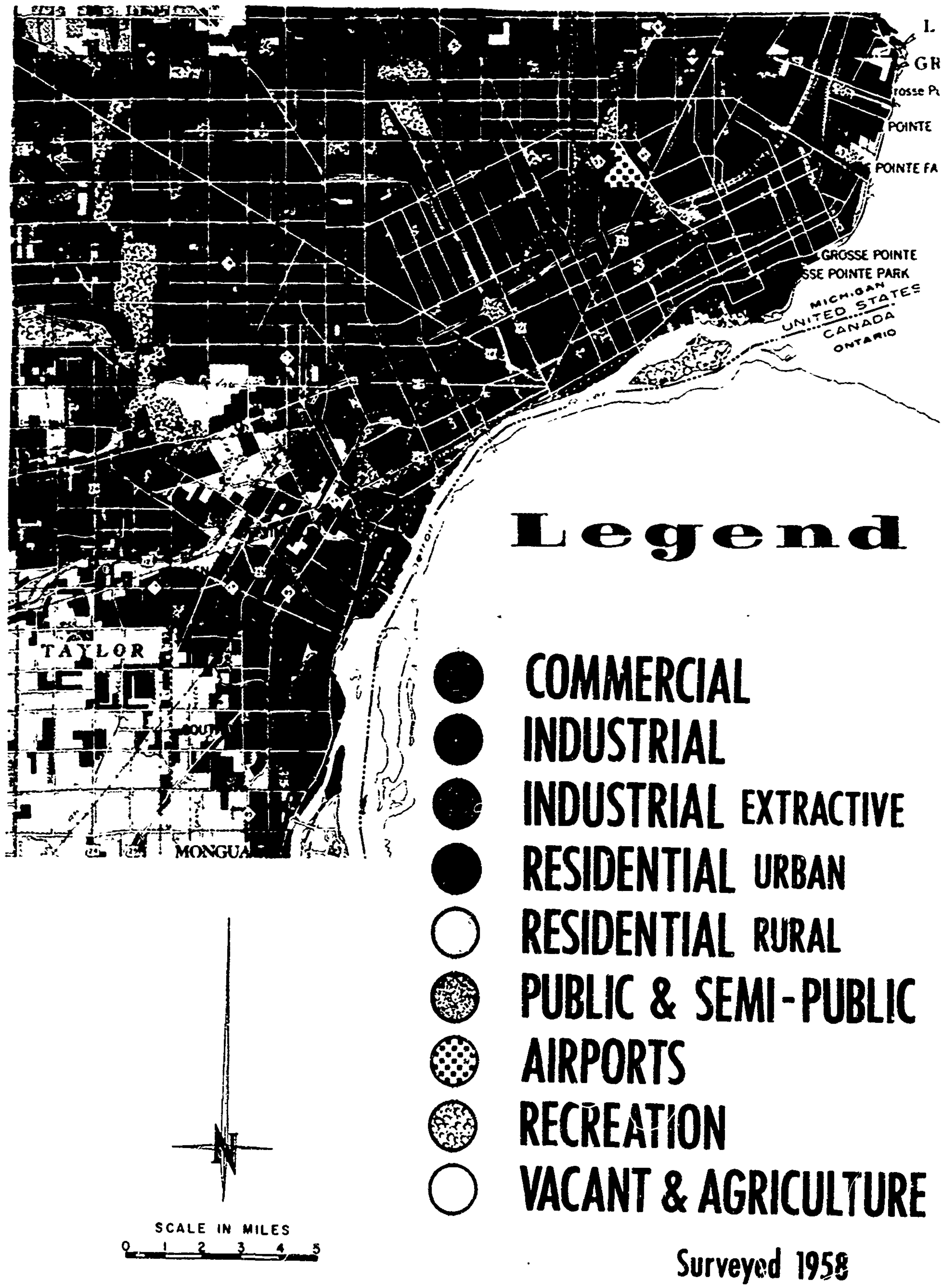

Fig. 12. Land Use Map for Detroit, Michigan

Fig. 13. Low Oblique Photo of Detroit, Michigan, Showing Central Commercial District

was subsequently obtained (from the Five-City Data Bank) and assembled into a mosaic (Fig. 14), which also served to identify vegetation locations and densities and, in general, the current complexion of the city.

DATA PROCESSING

The location of ground zero was first plotted on a quadrangle sheet by use of the geodetic coordinates given for the attack. This location was then transferred to a to-scale street map since the quadrangle sheet did not contain street information in sufficient detail.

The overpressures at various distances from ground zero were calculated for a 5-Mt surface burst by use of information contained in Ref. 12. (HOB curves are included in Appendix A — Fig. A-17.) These data points were then used to construct an overpressure vs distance curve (Fig. 15) and to plot overpressure isobars covering the city (Fig. 16).

The building data (address, use, type, number of stories, height, and area) were read from Sanborn maps (see sample Fig. B-2) and recorded on combination data and work sheets (see sample Fig. B-1). The volume and map number, street widths, and total area covered by the map were also recorded.

Overpressures on areas were found by scaling the distance to ground zero and using the overpressure vs distance plot, and checked against the overpressure isobar plot (Fig. 16).* This information enabled evaluation of the parameters in the formula presented in Table A-3 and determination of the proper percentage figure to apply (by use of proper debris chart** for building type — with or without fire) for calculation of structural debris volumes.

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* Overpressures used for calculating debris in the highly built-up downtown section do not take into account modifications of the air-blast pulse by shielding. In those portions of the city in which building height is significantly larger than the street width, Ref. 53 indicates that reduction of overpressure on the front face of a building can be greater than a factor of 2, and reduction in net translational force on a building can be as much as 80%.

** Although introducing a systematic error, the 20-Mt curves were used since none exist at present for a 5-Mt weapon. This error is insignificant in this example problem due to the location of the various building types with respect to the weapon (overpressures corresponded mostly to debris plateaus for the more drag-sensitive structures).

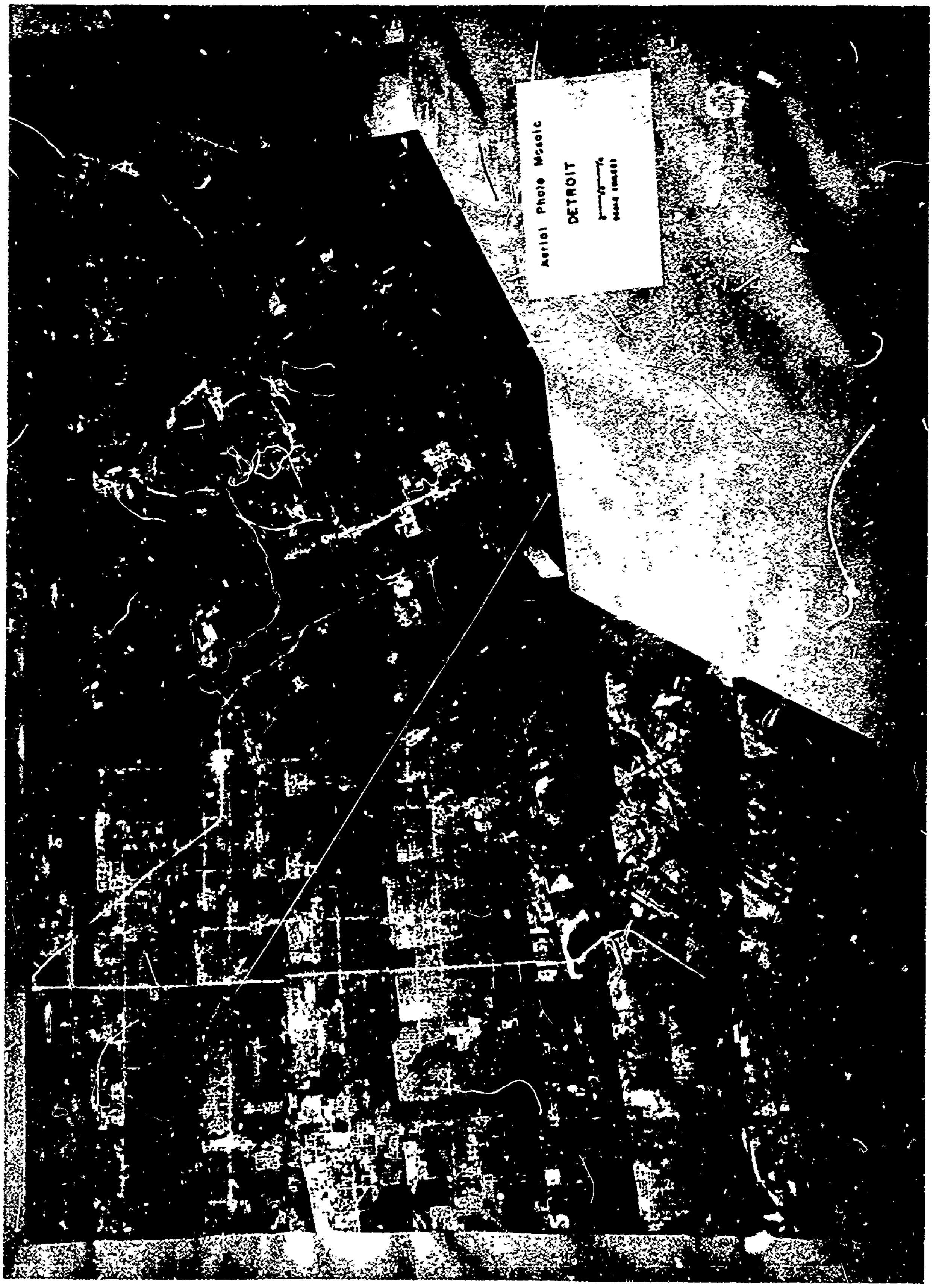

Fig. 14. Aerial Photo Mosaic of Detroit, Michigan (a pictorial representation)
Original Scale 1 to 20,000

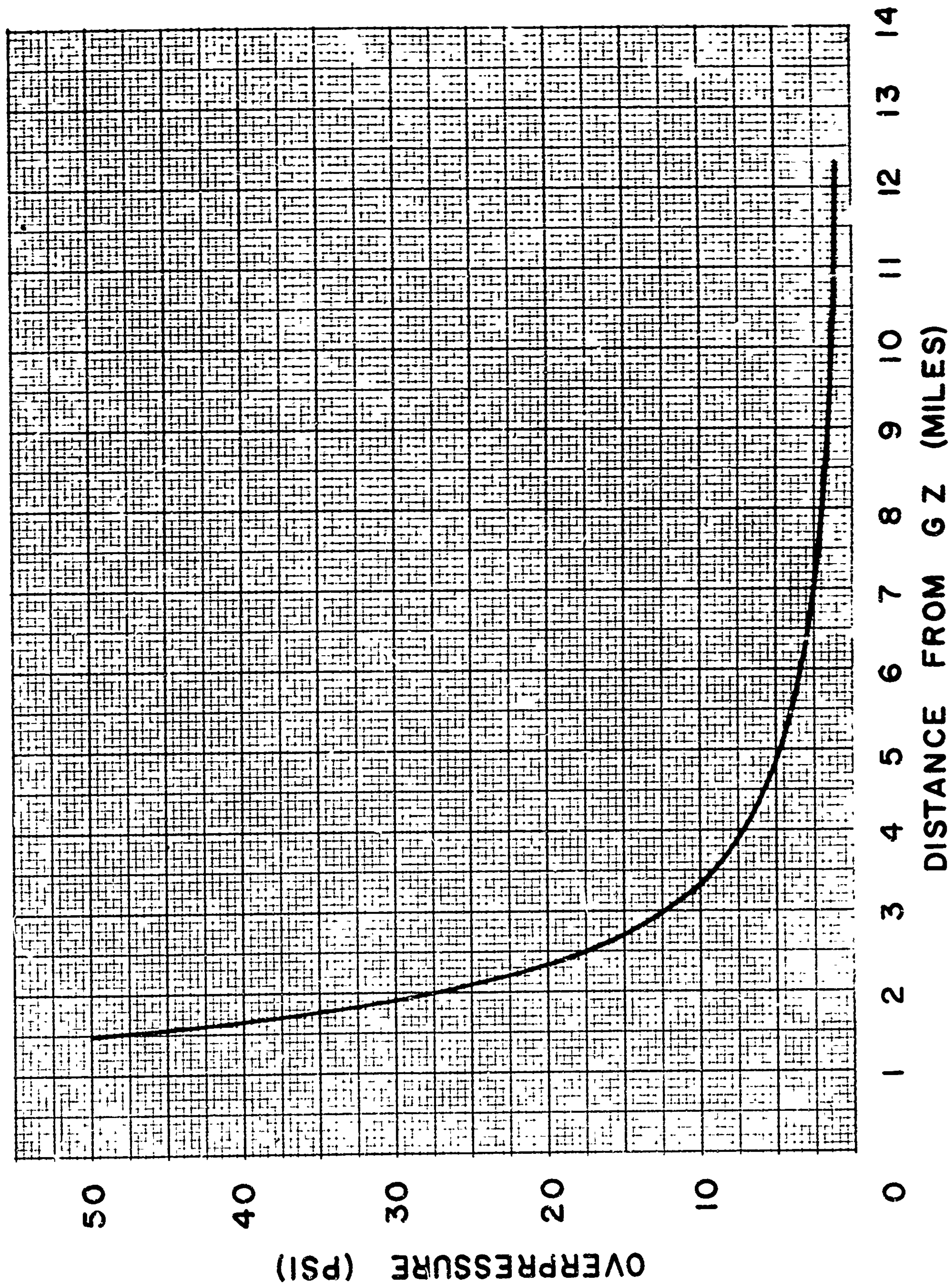

Fig. 15. Overpressure vs Distance for 5-Mt Surface Burst

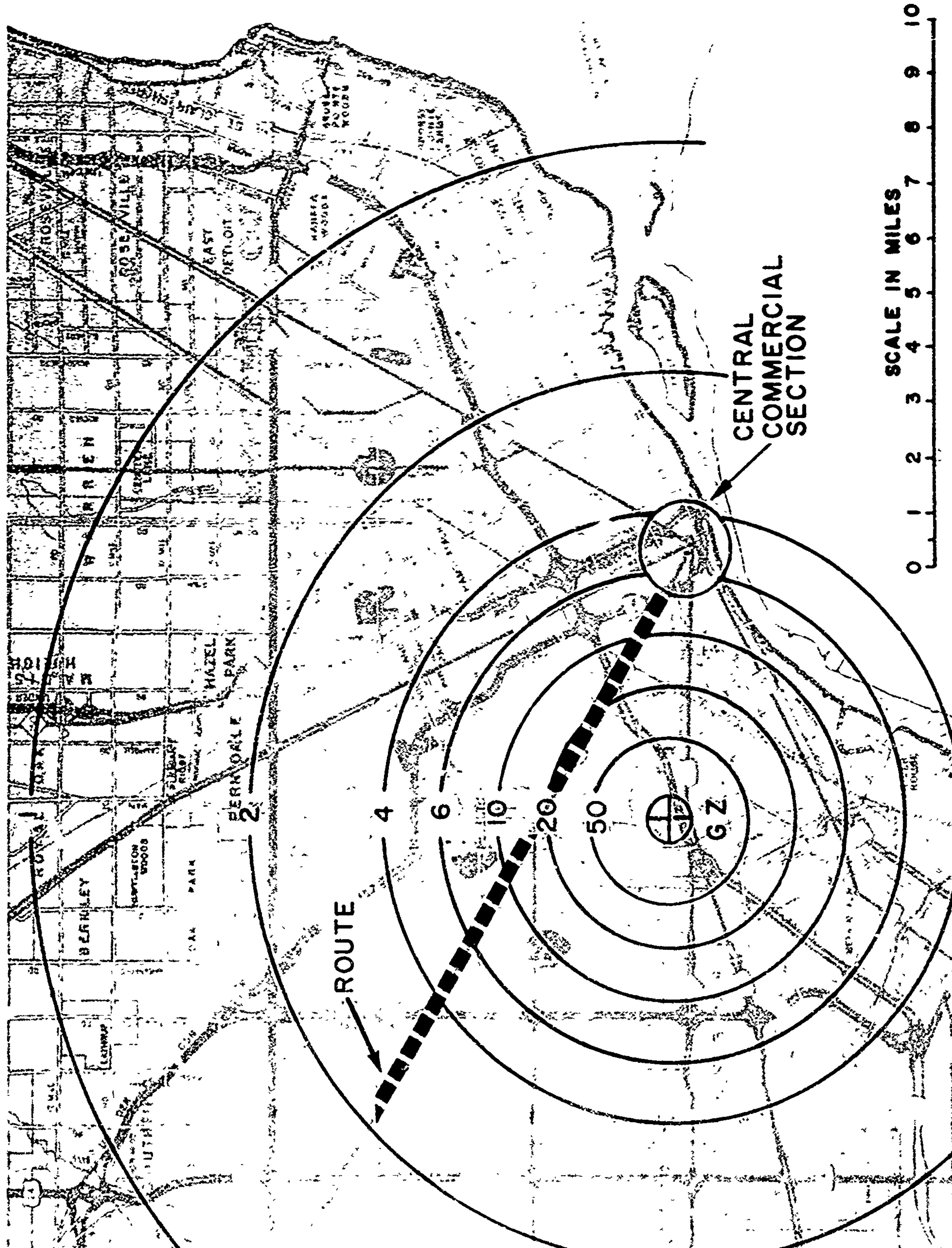

Fig. 16. Overpressure Isobars Over Detroit, Michigan, From a 5-Mt Surface Burst Attack

The volume of debris formed from the contents of the buildings was obtained by applying the criteria discussed in Section 3 and by use of Table A-2.

Determination of the debris volumes enabled calculation of debris depths. The debris was distributed uniformly over the area containing the structures when calculating debris depths for contour construction and distributed uniformly over the building site, including the street, when determining debris depths for construction of debris depth profiles along the selected route.

DEBRIS CONTOURS

Debris depth contours are plotted by employing a procedure similar to that used for making contour maps from topographic data. With a depth of 0 ft as the common datum, the debris depths at the control points were plotted* on an accurately scaled street map. Lines of constant debris depth were then drawn by interpolating between the control points and allowing for homogeneity and breaks in homogeneity of the various sections. This resulted in construction of two main debris contour maps for the city (Figs. B-3 and B-4), which show debris depth contours for blast acting alone and blast coupled with fire.

Debris distribution variations would exist in residential areas where buildings would not be completely destroyed by blast but would subsequently by destroyed by fire, the fire-formed portion remaining essentially on site and the air-blast portions being more widely distributed. To illustrate this effect, both the depth after fire for the air-blast-formed portion only and the total depth after fire (assuming even distribution) are recorded near each control point on Fig. B-4. (The depths obtained by evenly distributing the total amount of debris after fire were used for construction of this figure.)

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* The locations of these points are shown as small circles on the contour maps and are numbered to correspond to the volume and sheet number of the Sanborn map from which the building and street data supporting the point were derived.

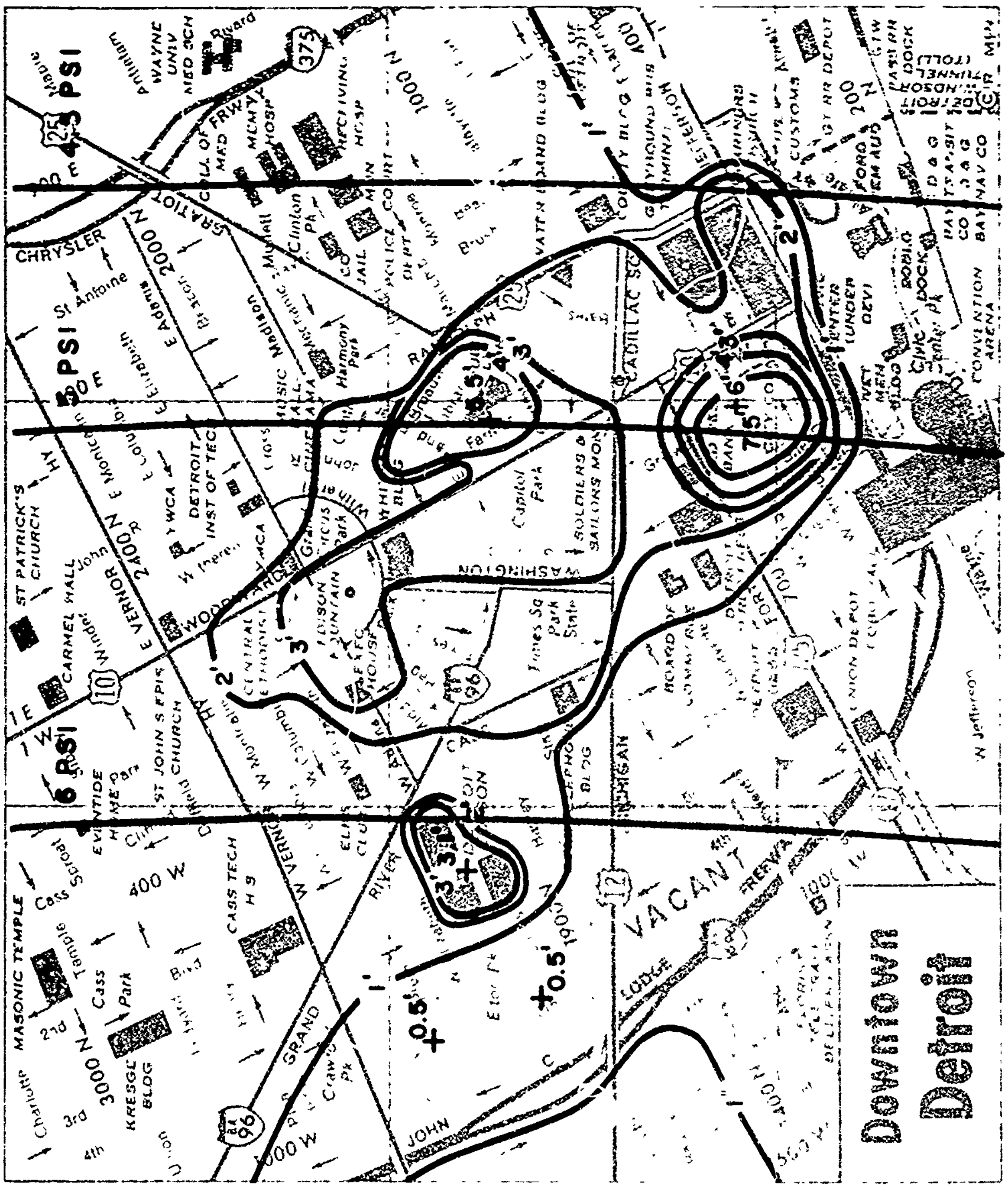

Fig. 17. Debris Contours – Downtown Section (Air Blast Only)

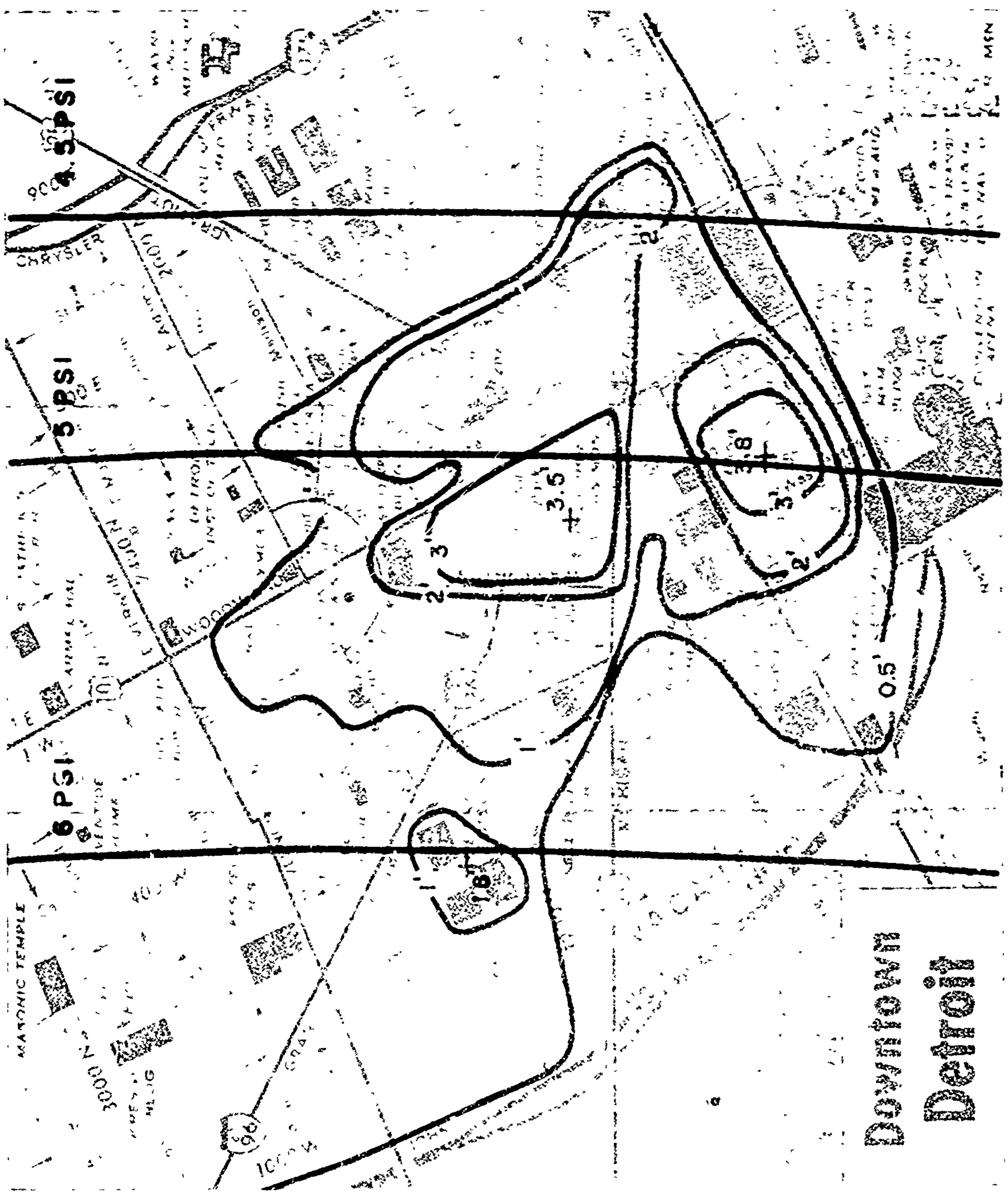

Fig. 18. Debris Contours — Downtown Section After Fire

An additional pair of contour maps (Figs. 17 and 18) were prepared for the downtown section to better illustrate steeper slope trends in debris depths in this highly built-up and rather heterogeneous section. Due to this heterogeneity and rapidly changing degrees of built-upness, many more control points were required to adequately define this area.

Although the overpressures (4 to 7 psi) on the downtown section are insufficient to cause heavy damage to the substantial multistory buildings, a considerable debris depth (2 to 10 ft) would be formed. The bulk of this debris is from the contents of buildings and the remainder (about 40 percent) is from interior and exterior building panels.

Note that fire both increased and decreased debris depths in this area. The increase was mainly caused by destruction of load-bearing masonry buildings and the decrease by consumption of combustible portions of the air-blast-formed debris.

To illustrate the effect of small businesses bordering various intermittently spaced streets in the outlying areas (see Fig. 12), Sections A-A and B-B (Fig. B-3) were drawn. It is noted that these businesses plus variations in street widths could cause either debris humps or debris troughs.

DEBRIS PROFILES ALONG ROUTE

The objective assumed when selecting the route in this example was to gain access by a reasonably direct route to the Detroit—Windsor Tunnel after entering the city from the northwest. A study of general city information (street map, land-use map, etc.) led to the selection of Grand River Avenue as possibly the best route. The on-site reconnaissance confirmed the feasibility of this general approach route and also made possible efficient selection of data (Sanborn maps) for profile control points.

These data were processed in a fashion similar to that for contour control point data in order to find debris volumes. These debris volumes were then distributed to the street and debris depths calculated. These

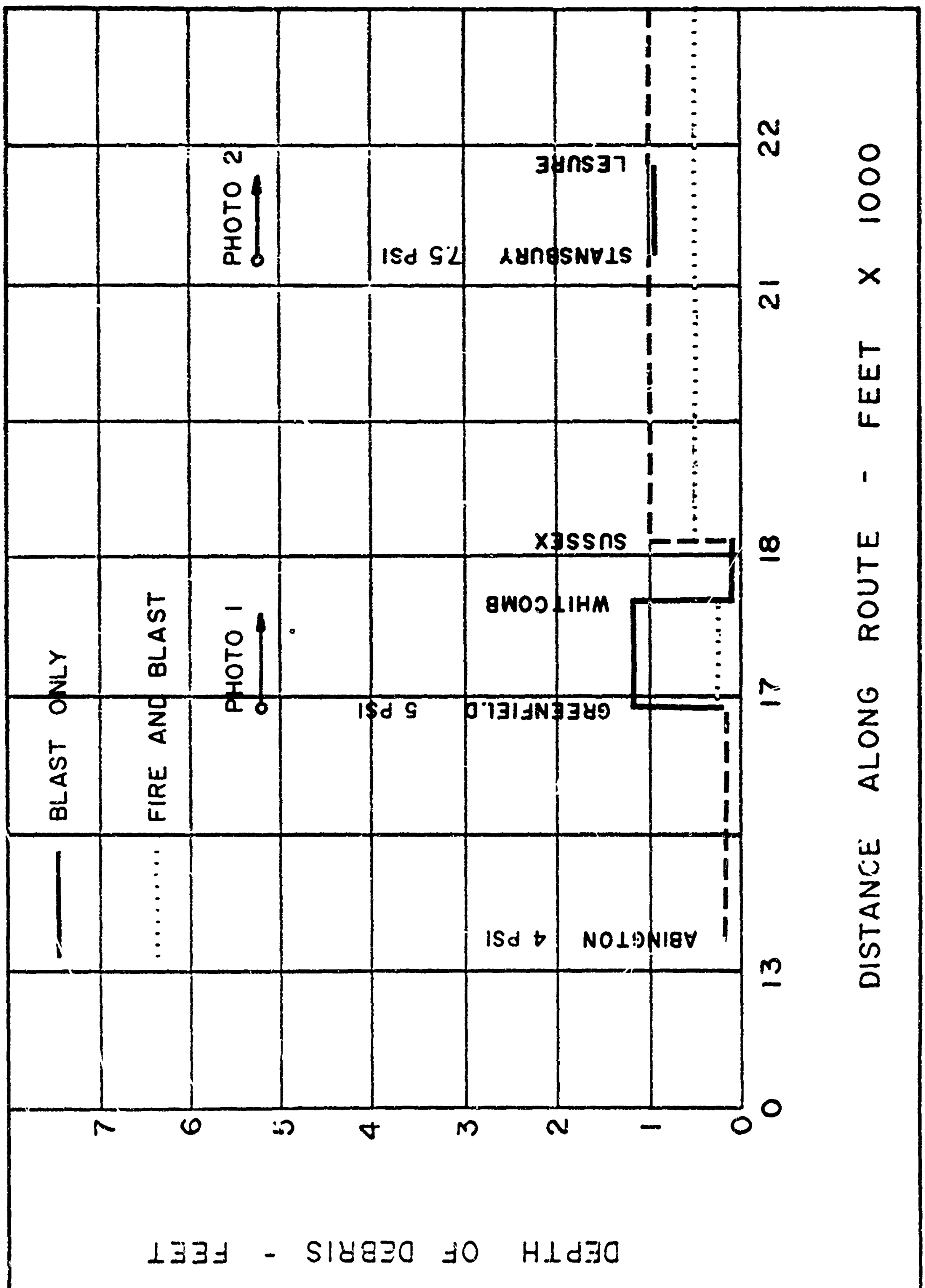

Fig. 19. Debris Profile, Abington to Lesure

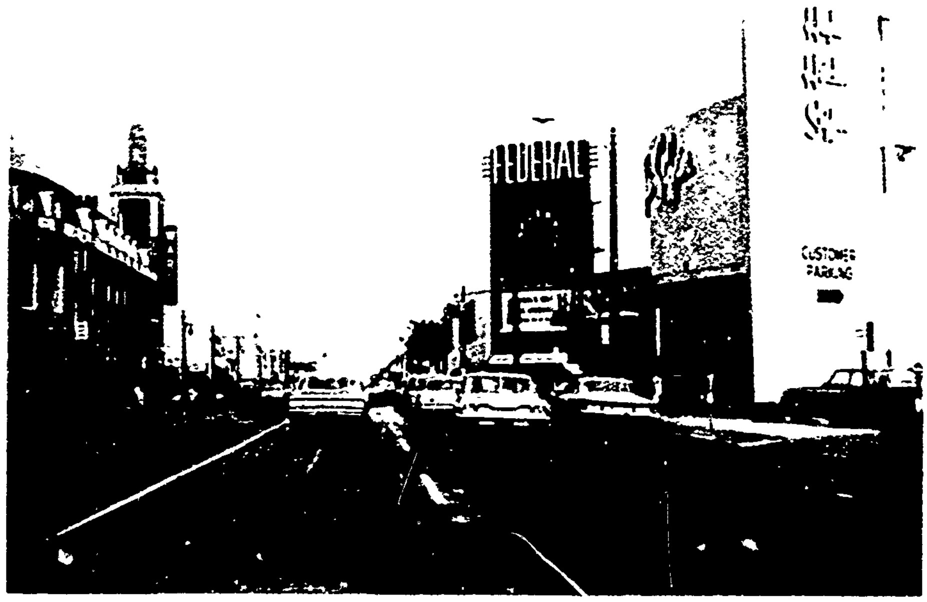

Photo 1 - 5 psi

Photo 2 - 7.5 psi

Fig. 20. Photos 1 and 2 Looking Down Grand River From Greenwood and Stansbury, Respectively

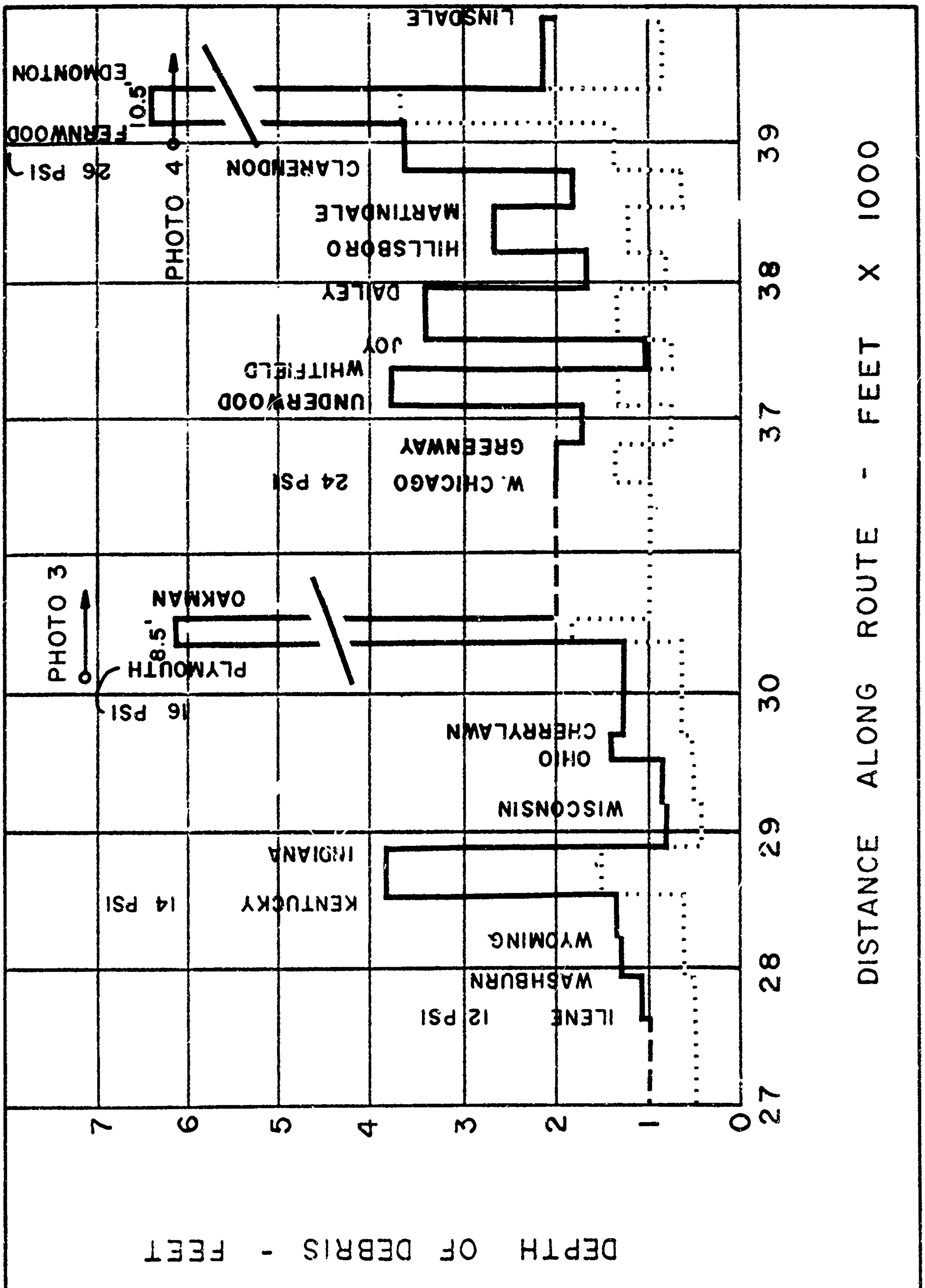

Fig. 21. Debris Profile, Ilene to Linsdale

Photo 3 - 16 psi

Photo 4 - 26 psi

Fig. 22. Views Looking Down Grand River From Plymouth and Fernwood, Respectively

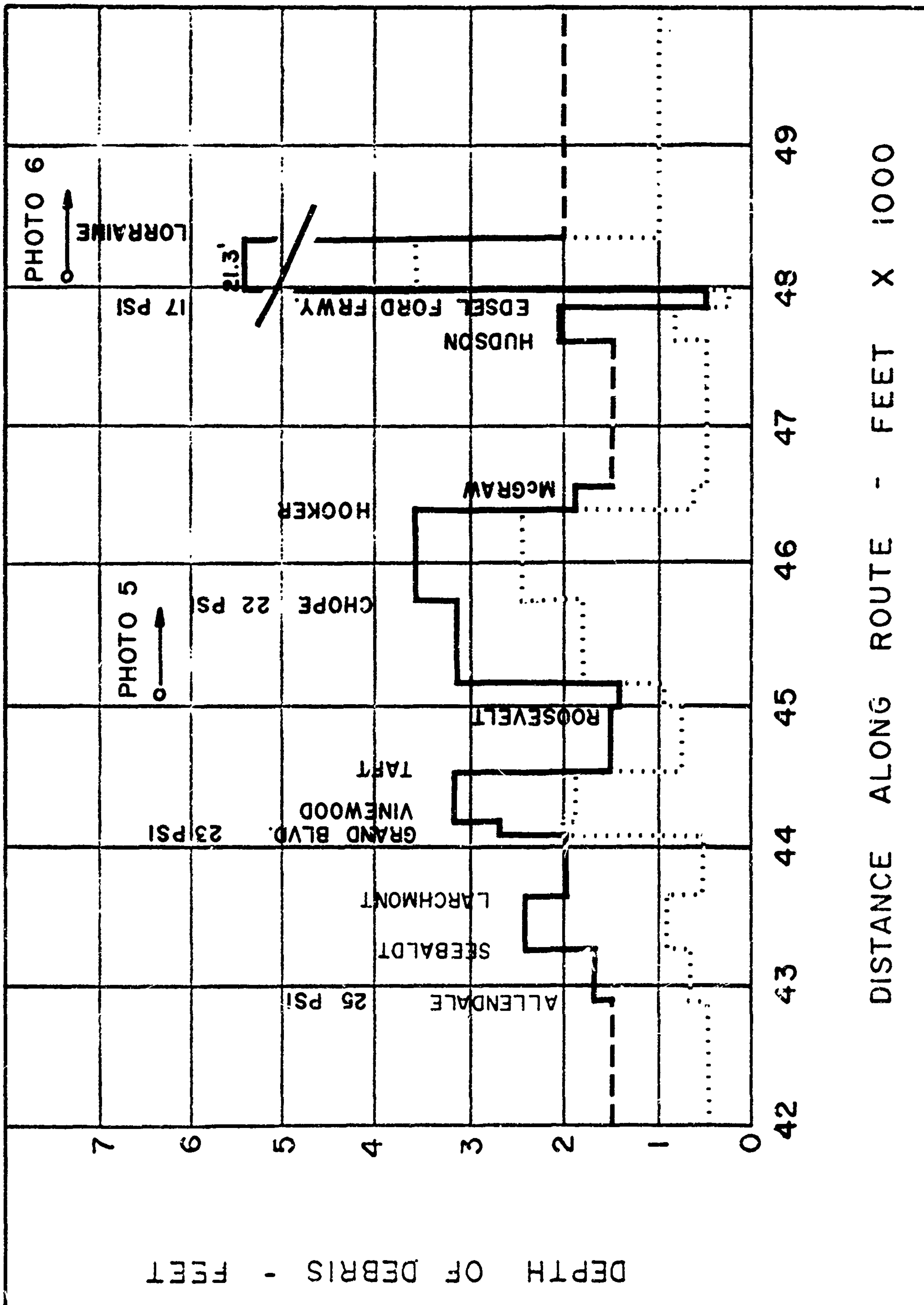

Fig. 23. Debris Profile, Allendale to Lorraine

Photo 5 - 22 psi

Photo 6 - 17 psi

Fig. 24. Views Looking Down Grand River From Intersections of Roosevelt St. and Edsel Ford Freeway, Respectively

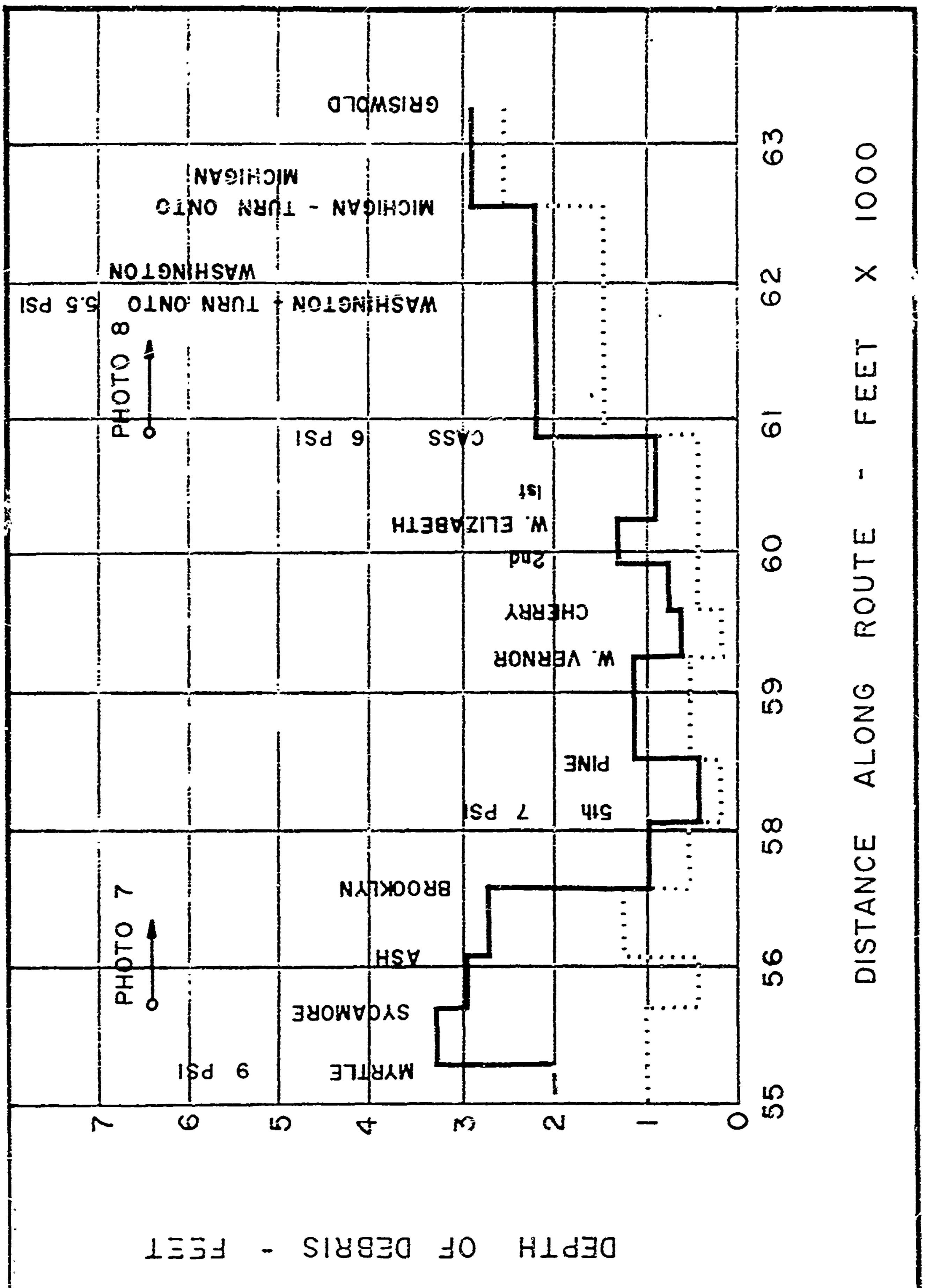

Fig. 25.. Debris Profile, Myrtle to Griswold

Photo 7 - 9 psi

Photo 8 - 6 psi

Fig. 26. Views Looking Down Grand River From Sycamore and Cass, Respectively

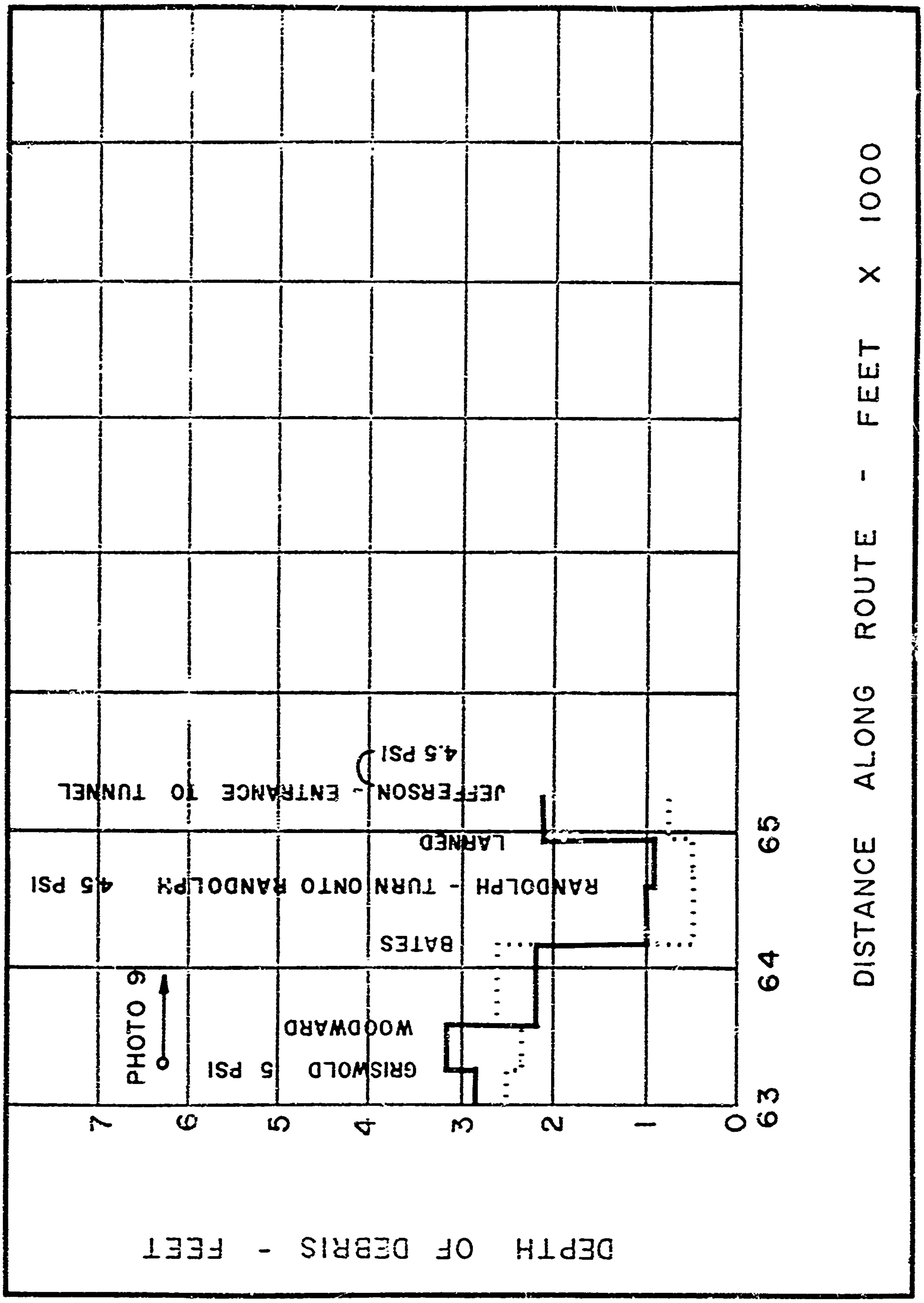

Fig. 27. Debris Profile, Griswold to Entrance of Detroit—Windsor Tunnel

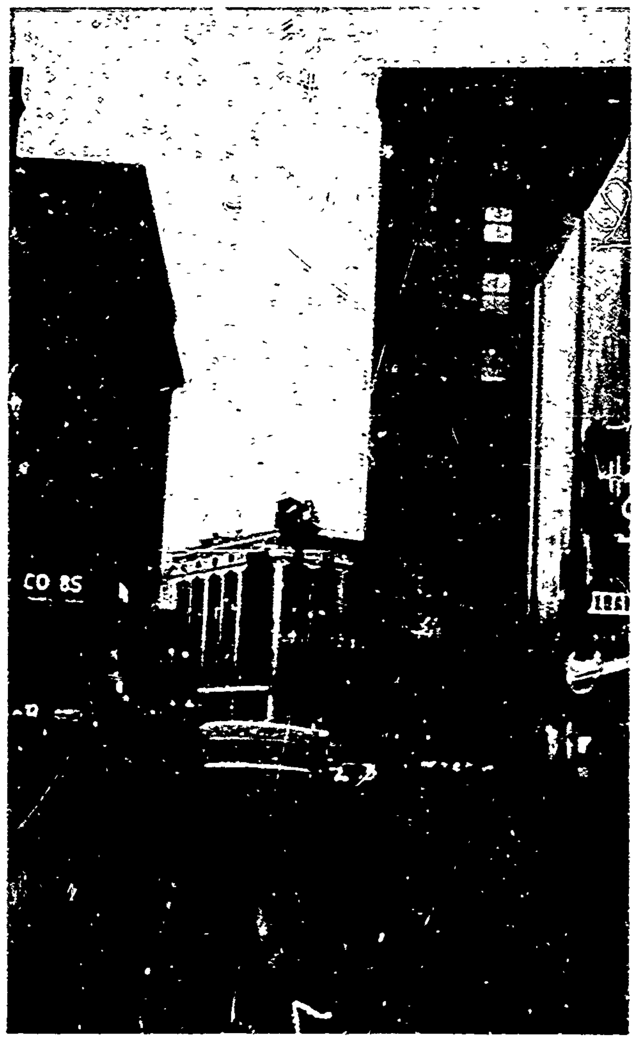

Photo 9 - 5 psi

Fig. 28. View Looking Down Grand River From Griswold

depths were plotted with respect to distance from the starting point of the route (the intersection of Grand River Avenue and W. McNichols Road) and debris profiles drawn. The debris depth profiles and illustrative photographs are presented in Figs. 19 through 28. The long dash lines indicate length of route for which no data were obtained, since only slight changes were observed in these sections and their detailed treatment would be of little value. The debris depths with fire effects included are shown as short-broken lines. Cross streets and photo references are also noted.

Grand River Avenue goes through predominantly residential areas until the all-commercial downtown section is reached and is generally lined through its length by commercial frontage. The debris along the residential—commercial section (Figs. 19 through 24) is on the average 45 percent from building contents and 55 percent from structural components. This is reversed in the central commercial section, however, with 60 percent being from contents and 40 percent from structural components. The presence of fire changes these percentages, respectively, to 5 and 95 for the residential—commercial sections and 25 and 75 for the central commercial section.

Very high debris depth peaks, 8.5 ft, 10.5 ft, and 21.3 ft, are noted between Plymouth and Oakman Blvd., Fernwood and Edmonton Streets, and the Edsel Ford Freeway and Lorraine Street (see Figs. 21 and 23). In each case these peaks are due to destruction of a single warehouse building (a 9-story and a 6-story reinforced concrete frame building with masonry panels, and a 4-story load-bearing masonry building). These buildings appear in Photos 3, 4, and 6.

It would be wise to bypass these areas by detouring through adjacent residential streets containing an average of less than 1.25 ft of debris,* as can be seen from the debris contour map (Fig. B-3). Feasible detours are shown in Figs. 29, 30, and 31.

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* For the sake of simplicity, debris depths from air blast only will be considered in rerouting discussion.

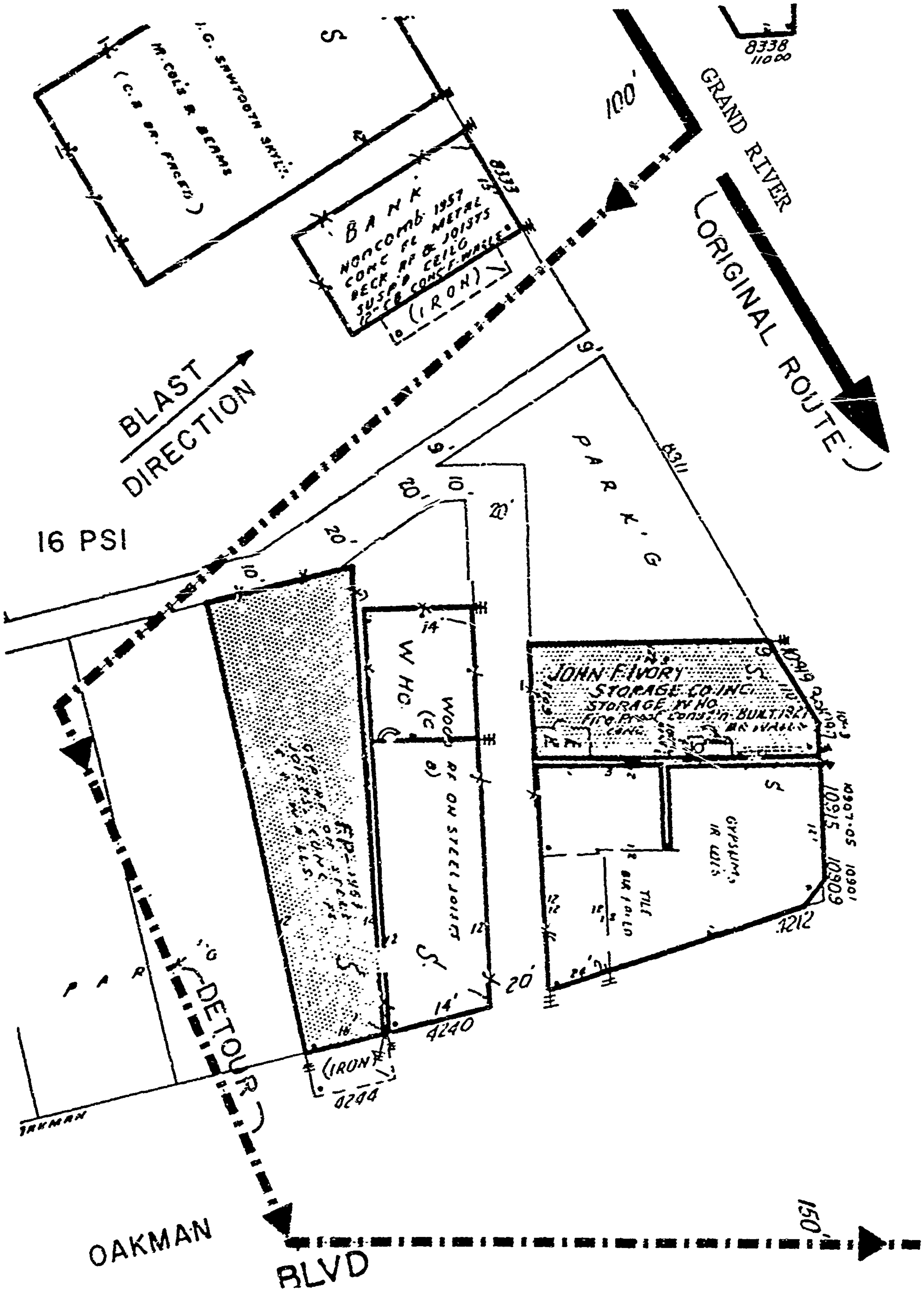

Fig. 29. Detour I

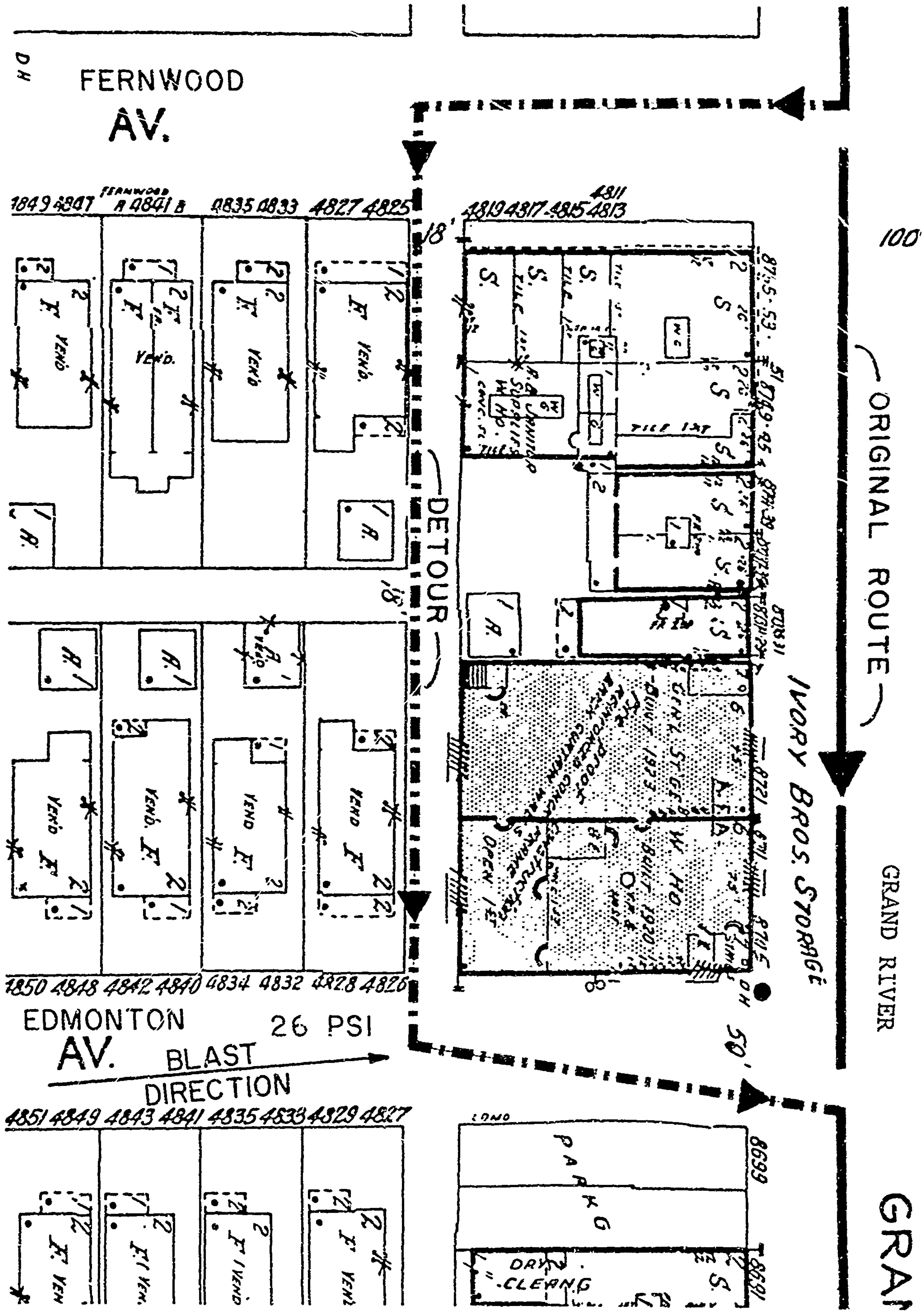

Fig. 30. Detour II

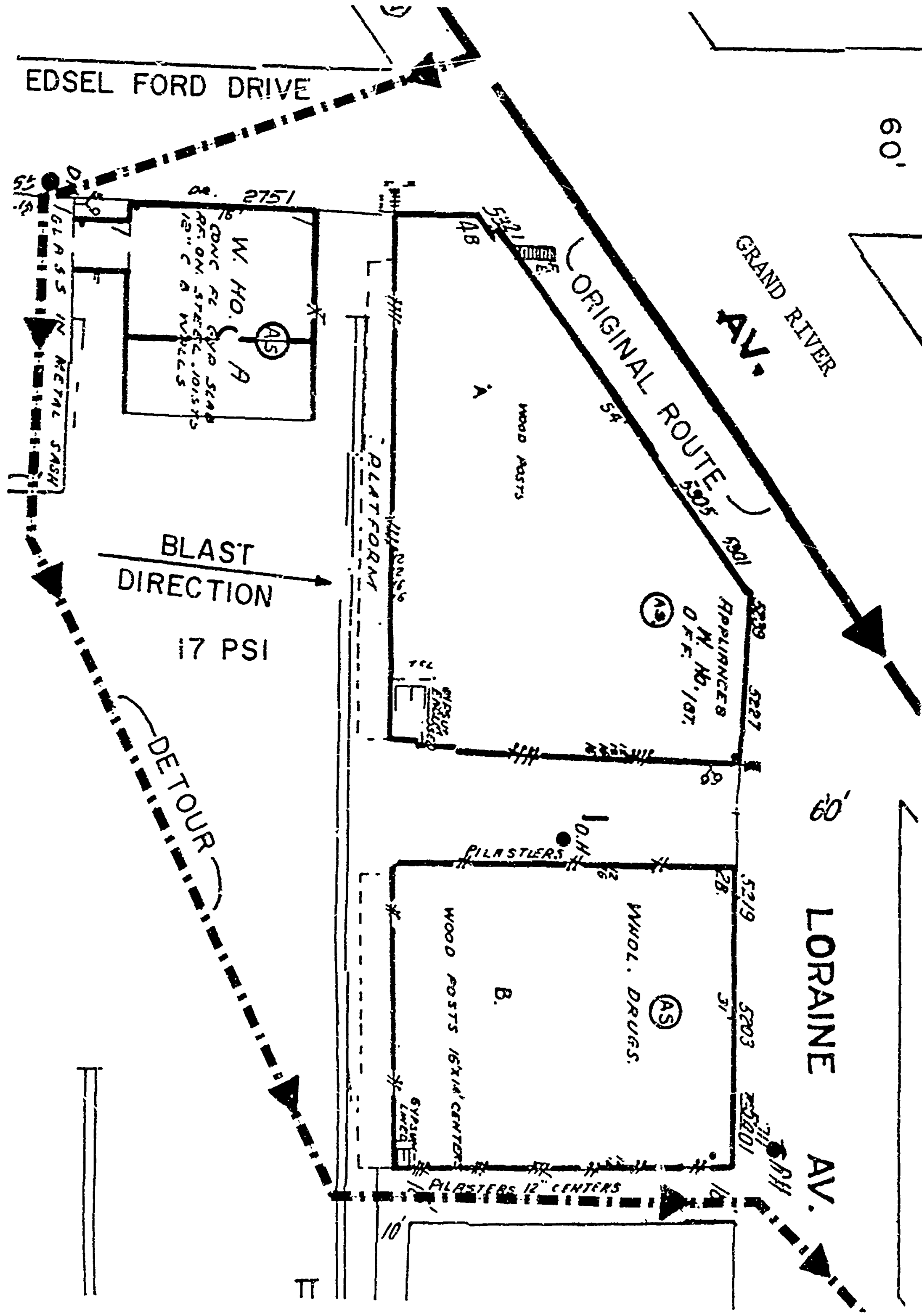

Fig. 31. Detour III

Even more desirable would be a less obstructed route through the downtown section. Referring again to the debris contour map, it is noted that shallower debris depth areas do exist in the downtown section, with very little travel distance involved to reach them. Some areas, due to the current urban renewal program, are totally denuded of buildings. One of these areas is shown on the low oblique photo (Fig. 33) and can also be seen on the larger scale aerial photo covering the downtown section (Fig. 34). A study of these photographs and the contour map for the downtown section (Fig. 32) enabled selection of the alternate route sketched on Figs. 32, 33, and 34, which takes advantage of vacant areas and avoids areas containing greater debris depths.

For comparison, a profile of the alternate route is shown in Figs. 35 and 36. Also, to illustrate the effectiveness of rerouting, volumes of debris (air blast only) in a 12-ft lane through the detours and detoured sections were calculated and are as follows:

Detour	Volume in Detour V_d (ft^3)	Volume in Original Route Section V_o (ft^3)	Ratio $\frac{V_o}{V_d}$
I	10,860	64,000	5.9
II	7,650	35,160	3.9
III	13,790	101,400	7.4
IV (Downtown)	87,380	145,450	1.7
TOTAL	119,680	345,950	2.9

This reduced the amount of debris in those potentially troublesome sections by 227,000 ft^3, a factor of about 2.9.

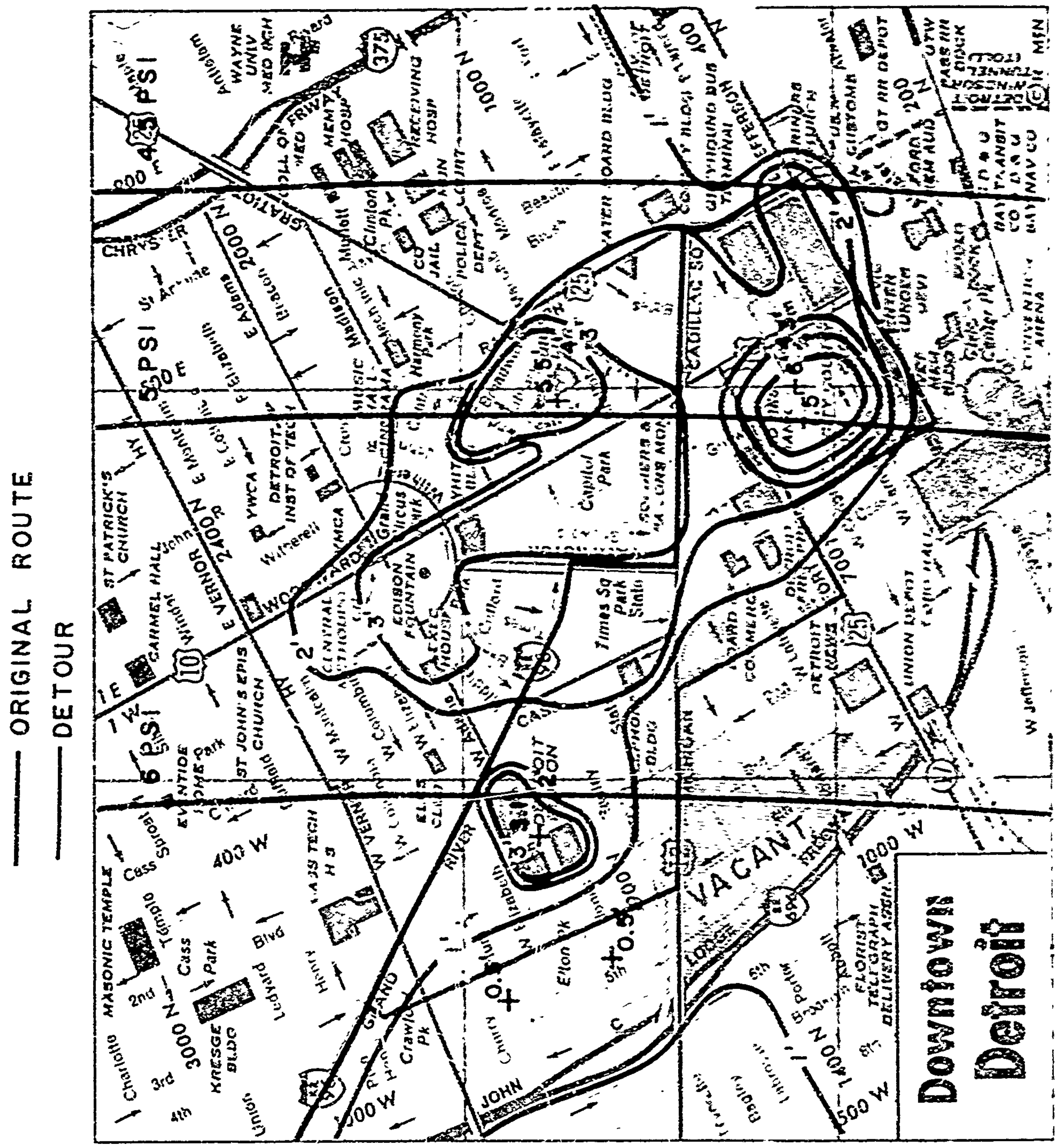

Fig. 32. Detour IV — Downtown Section

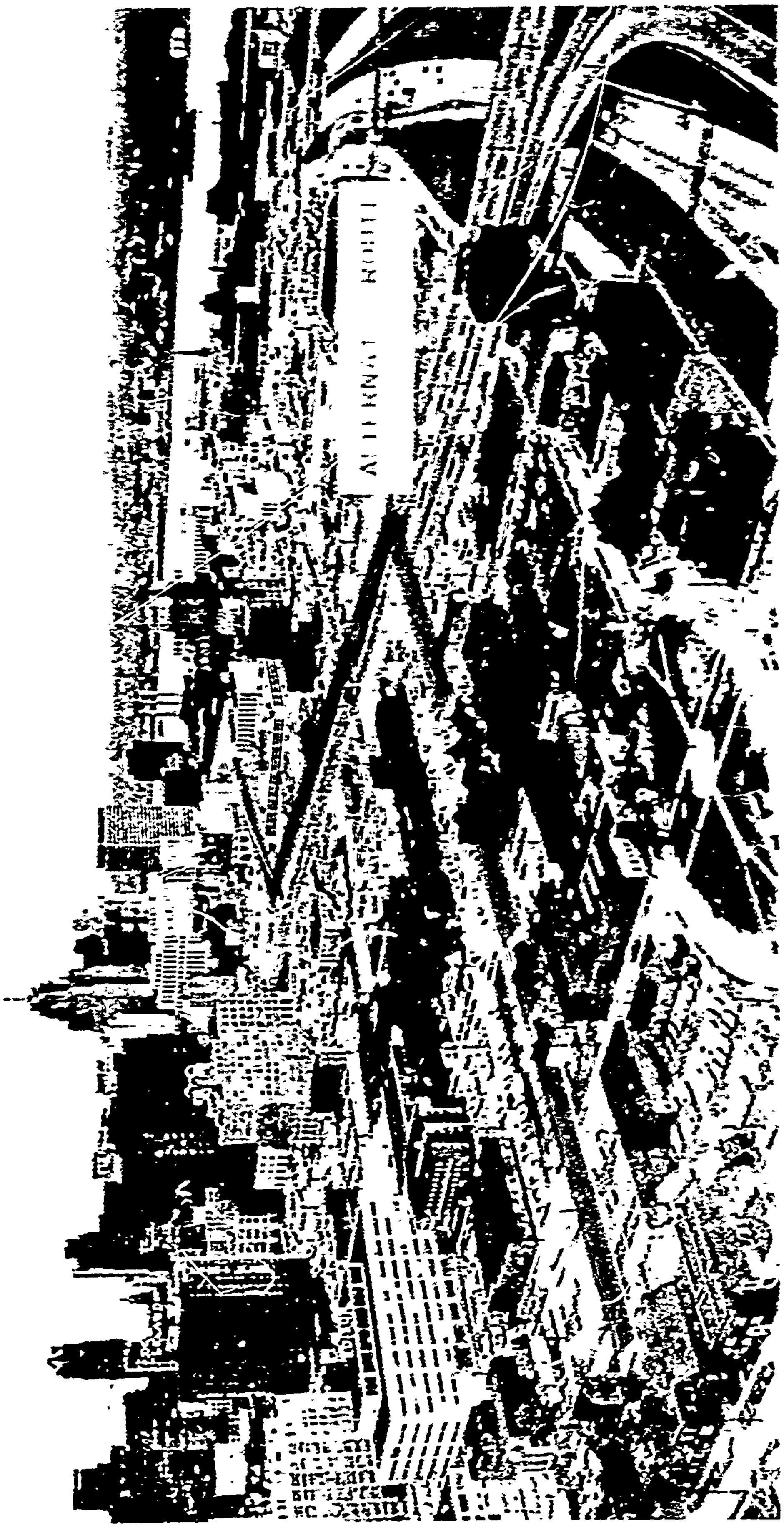

Fig. 33. Alternate Route Through Central Section (wide red line). Low Oblique Looking NE

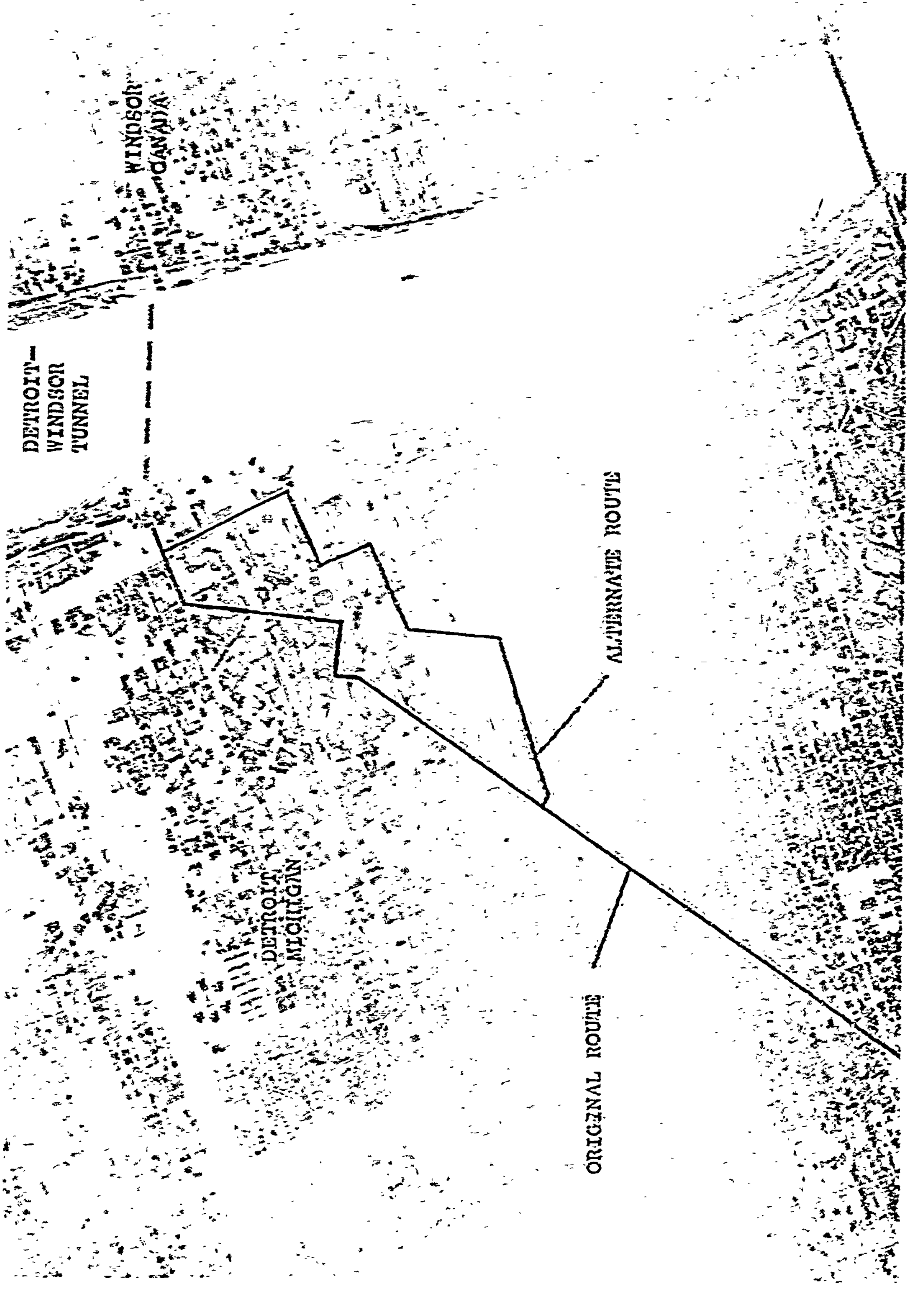

Fig. 34. Original Route and Detour IV Superimposed on Aerial Photo of Downtown Section of Detroit

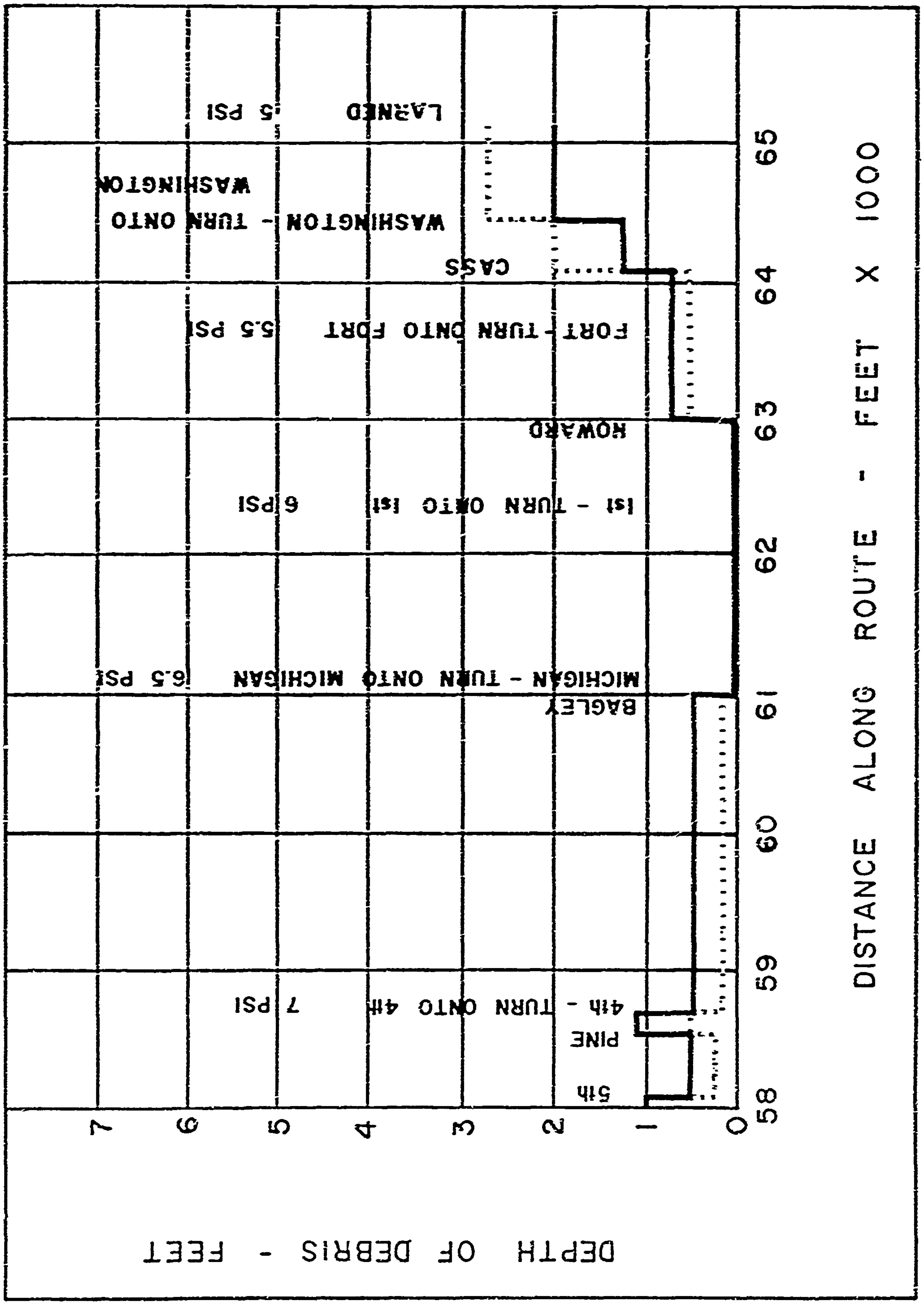

Fig. 35. Debris Profile, Alternate Route (Detour IV)

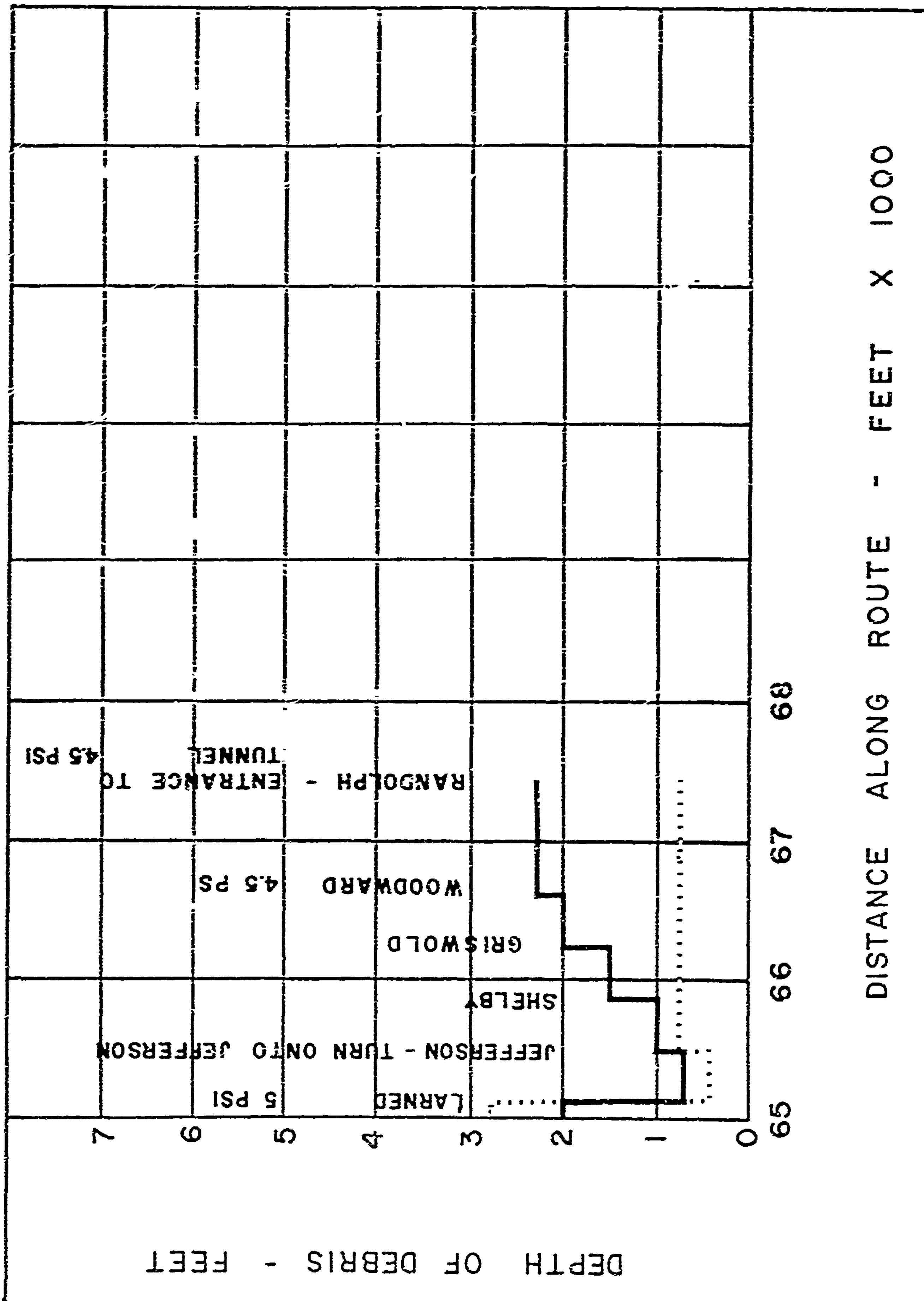

Fig. 36. Debris Profile, Alternate Route (Detour IV)

Section 6

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The additional curves, building contents criteria, assembled data, empirical formula, and other improvements provided in this phase of development have added to the accuracy and versatility of the debris prediction model.

The example problem presented in this report illustrates the potential of this model for general debris investigations (debris contours) as well as specific detailed investigations (debris depths along a route).

The example problem provided an excellent illustration of the advantages that can be gained by selecting alternate routes detouring sections or areas of greater debris depth.

RECOMMENDATIONS

To permit alternate routes to be evaluated and selected more quickly, and to permit the more rapid construction of depth contours, with a higher degree of optimization and efficiency, it is recommended that the now cumbersome debris depth calculations be automated.

To improve the accuracy of these depth calculations, it is recommended that procedures for estimating the distribution of debris with respect to the donor building be substantially improved.

To provide more versatility (without losing accuracy), it is recommended that debris charts for a more complete range of weapon sizes and for some additional structure types frequently encountered (such as the hybrid structures containing shear walls acting compositely with a structural steel frame) be prepared. Even though damage data do not exist for these buildings, failure can be estimated theoretically, but with more work and a smaller degree of assurance as to accuracy.

To improve the predictions of debris depths in highly built-up city areas, it is recommended that the blast wave shielding afforded buildings by neighboring buildings be further studied.

Section 7
REFERENCES

1. Edmunds, J. E., C. K. Wiehle, and K. Kaplan, Structural Debris Caused by Nuclear Blast, URS 639-4, Contract No. OCD-PS-64-19, URS Corporation, Burlingame, Calif., Oct 1964

2. Rotz, J. V., J. E. Edmunds, and K. Kaplan, Effects of Fire on Structural Debris Produced by Nuclear Blast, URS 639-9, Contract No. OCD-PS-64-19, URS Corporation, Burlingame, Calif., Jan 1965

3. U.S. Strategic Bombing Survey, Effects of the Atomic Bomb on Nagasaki, Japan, Vol. I, June 1949

4. U.S. Strategic Bombing Survey, Effects of the Atomic Bomb on Nagasaki, Japan, Vol. II, June 1949

5. U.S. Strategic Bombing Survey, Effects of the Atomic Bomb on Nagasaki, Japan, Vol. III, June 1949

6. U.S. Strategic Bombing Survey, The Effects of the Atomic Bomb on Hiroshima, Japan, Vol. I, May 1947

7. U.S. Strategic Bombing Survey, The Effects of the Atomic Bomb on Hiroshima, Japan, Vol. II, May 1947

8. U.S. Strategic Bombing Survey, The Effects of the Atomic Bomb on Hiroshima, Japan, Vol. III, May 1947

9. Capabilities of Nuclear Weapons (U), Part II - Damage Criteria, Defense Atomic Support Agency, 1962 (C)

10. Newmark, N. M., "An Engineering Approach to Blast Resistant Design," Trans ASCE, Vol. 121, paper no. 2788, pp. 45–64, 1956

11. Norris, C. H., et al., Structural Design for Dynamic Loads, McGraw-Hill Book Company, Inc., New York, New York, 1959

12. Glasstone, S. (ed.), Effects of Nuclear Weapons, U.S. Government Printing Office, Washington, D.C., 1962, Rev. 1964

13. Gradwohl, A. J., A Survey of the Sizes, Weights, and Locations of Equipment and Stored Goods in Light Industrial Plants, Project Civil, Institute of Engineering Research, University of California, Contract No. GD-GA-56-57, 22 Nov 1957

14. Dunham, J. W., G. N. Brekke, and G. N. Thompson, National Bureau of Standards, Live Loads on Floors in Buildings, Building Materials and Structures Report 133, 19 Dec 1952

15. Ingberg, S. H., J. W. Dunham, and J. P. Thompson, National Bureau of Standards, Combustible Contents in Buildings, Building Materials and Structures Report 149, 25 July 1957

16. Ingberg, S. H., J. W. Dunham, and J. P. Thompson, National Bureau of Standards, Fire Resistance Classification of Structures, Building Materials and Structures Report BMS 92, 7 Oct 1942

17. American Iron and Steel Institute, Fire Protection Through Modern Building Codes, 1961 edition

18. West Coast Conference of Building Officials, Uniform Building Code, 1964 edition

19. Phung, P. V. and A. B. Willoughby, Prediction Models for Fire Spread Following Nuclear Attacks, URS 641-6, Contract No. OCD-PS-64-48, URS Corporation, Burlingame, Calif., Jan 1965

20. Bond, Horatio (ed.), Fire and the Air War, National Fire Protection Assoc., Boston, Mass., 1946 (second printing, 1951), pp. 46, 88, 89, 91

21. Russell, Hubert D. et al., Complete Story of San Francisco Horror, 1906

22. Angle, Paul M., (ed.), The Great Chicago Fire, Chicago Historical Society, 1946

23. Bronson, William, The Earth Shook, The Sky Burned, first ed., Doubleday and Co., Inc., Garden City, New York, 1959

24. Kogan, Herman and Loyd Wendt, Chicago, A Pictorial History, Dutton, New York, 1958

25. Shorter, W. G., Toronto Fire of 1904, NRL 7830, National Research Council, Div. of Building Research, Ottawa, Canada, Mar 1964

26. Himmelwright, A. L. A., San Francisco Earthquake and Fire 1906, Robling Construction Co., N.Y., 1906, pp. 30—256

27. Ahlers, E. G., Debris Clearance Study, Final Report, IIT Research Institute, Technology Center, Chicago, Illinois, Sept 1963

28. National Board of Fire Underwriters, Fire Resistance Ratings of Less Than One Hour, May 1964

29. National Board of Fire Underwriters, Fire Resistance Ratings (Beam, Girder and Truss Protections, Ceiling Constructions, Roof Constructions, Walls and Partitions), Apr 1959

30. Underwriters Laboratories Inc., Building Materials List

31. Brode, Harold L., Thermal Radiation From Nuclear Explosions, Rand Corp., Santa Monica, Calif., Aug 1963

32. Rogers, Jack C., Ignition of Materials by Large Yield Nuclear Weapons for Various Burst Heights and Atmospheric Conditions, Contract No. OCD-OS-62-135, Stanford Research Institute, Menlo Park, Calif., May 1963

33. Martin, S. and A. Broido, Thermal Radiation and Fire Effects of Nuclear Weapons, USNRDL-TR-65-2, DASA 1376, U.S. Navy Radiological Defense Laboratory, San Francisco, Calif., 10 May 1963

34. Strope, Walmer E. and John F. Christian, Fire Aspects of Civil Defense, Research Report No. 9, Office of Civil Defense, Washington, D.C., May 1964

35. Strope, Walmer E. and John F. Christian, Fire Aspects of Civil Defense, TR-25, July 1964

36. Sevin, E., Tests on the Response of Wall and Roof Panels and the Transmission of Load to Supporting Structure, WT 724*, Operation Upshot-Knothole, May 1955

37. Longmire, R. M. and R. D. Mills, Navy Structures (U), WT 729*, Operation Upshot-Knothole, May 1955 (C)

38. Taylor, B. J., Blast Effects of Atomic Weapons Upon Curtain Walls and Partitions of Masonry and Other Materials, WT 741*, Operation Upshot-Knothole, Aug 1956

39. Byrnes, J. B., Effects of an Atomic Explosion on Two Typical Two-Story and Basement Wood-Frame Houses, WT 792*, Operation Upshot-Knothole, September 1953

40. Sinnamon, G. K., et al., Effect of Positive Phase Length of Blast on Drag and Semidrag Industrial Buildings, Part I, Operation Teapot, WT 1129*, December 1958

41. Johnston, Bruce G., Damage to Commercial and Industrial Buildings Exposed to Nuclear Effects, Operation Teapot, WT 1189*, February 1956

42. Randall, P. A., Damage to Commercial and Special Types of Residence Exposed to Nuclear Effects, Operation Teapot, WT 1194*, March 1961

43. Bultmann, E. H., E. Sevin, and T. H. Schiffman, Blast Effects on Existing Upshot-Knothole and Teapot Structures, Operation Plumbbob, WT 1423*, May 1960

44. Hayden, C. L., U.S. Navy Structures Appendix E-J, WT 23*, Operation Greenhouse, February 1952

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* Reports with "WT" designation are Weapons Test Reports, obtainable from Defense Atomic Support Agency, Washington, D.C.

45. Hayden, C. L., U.S. Navy Structures, Appendix L, Postshot Photographs, WT 25*, Annex 3.2, Operation Greenhouse, February 1952

46. Pettitt, B. E., Scientific Director's Report Annex 3.3 U.S. Air Force Structures, WT 29*, Operation Greenhouse, August 1951

47. Pettitt, B. E., U.S. Air Force Structures Appendix A, Section II, App C and D, WT 30*, Operation Greenhouse, August 1951

48. Pettitt, B. E., U.S. Air Force Structures Appendix F, Annex 3.3, WT 39*, Operation Greenhouse, August 1951

49. U.S. Army Structures, Appendix 10, WT 56*, Annex 3.1, Operation Greenhouse, July 1951

50. Hayden, C. L., U.S. Navy Structures, WT 91*, Operation Greenhouse, June 1952

51. Army Structures Test Appendix 12, Results of Second Engebi Shot, WT 95*, Annex 3.1, Operation Greenhouse, August 1951

52. Sinnamon, C. K., J. D. Haltiwanger, and N. M. Newmark, Effect of Length of Positive Phase of Blast on Drag Type and Semidrag-Type Industrial Buildings (U), WT 1325*, Operation Redwing, August 1959 (SFRD)

53. Willoughby, A. B., K. Kaplan, and J. Zaccor, Blast Shielding in Complexes (U), Broadview Research Corporation (now URS Corporation) for Air Force Special Weapons Center, Contract No. AF 29)601)-1149, BRC 127-1D, July 1959 (C)

Appendix A

CONSOLIDATION OF DEBRIS MODEL DATA

Appendix A

CONSOLIDATION OF DEBRIS MODEL DATA

This Appendix is a consolidation of the debris charts developed to date and other data used in the operation of the debris model. Also included and discussed are time saving developments which have evolved through use of the model.

Description, sources, and location of this information are as follows:

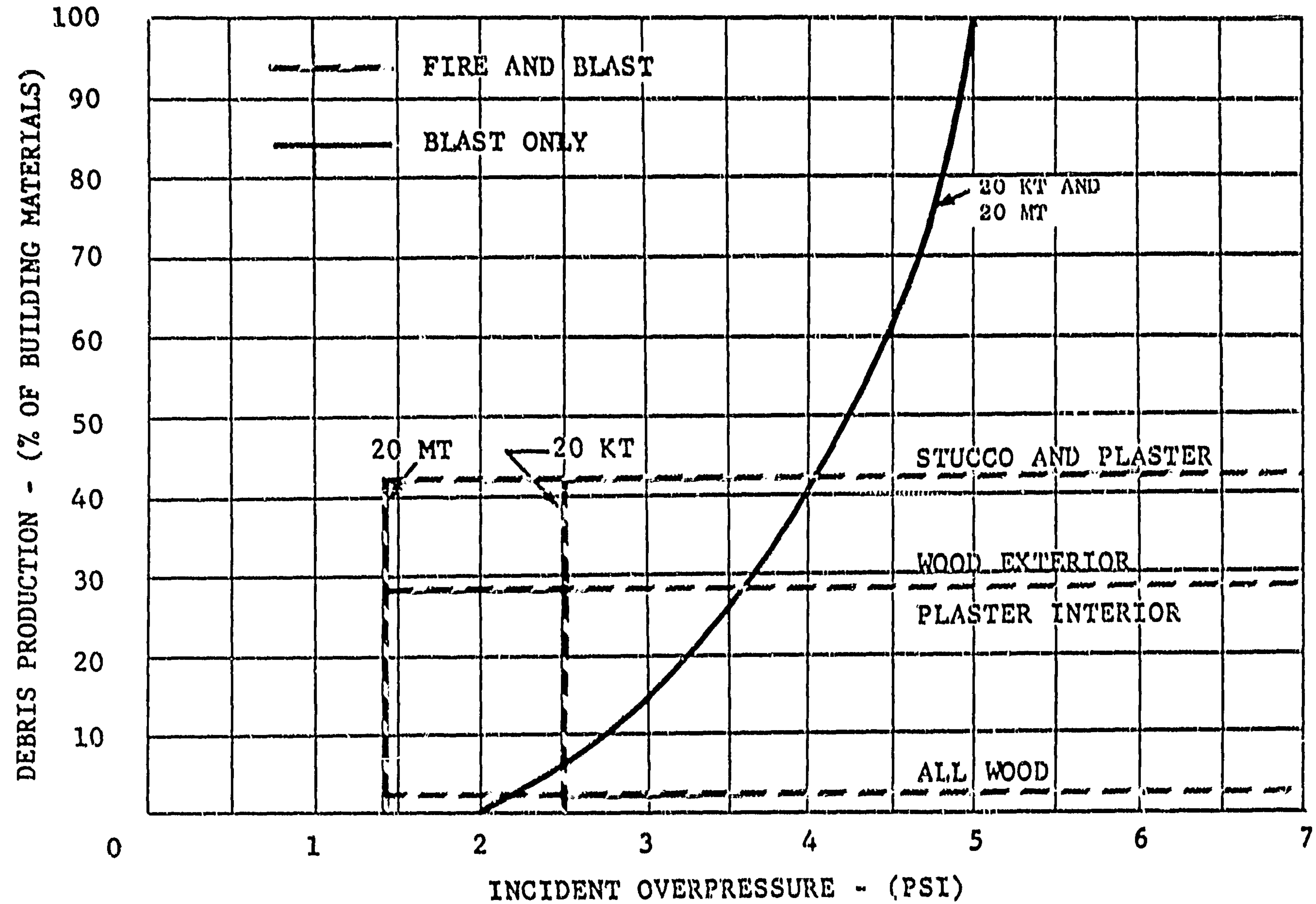

Fig. A-1. Coupled Fire and Blast Percent Debris vs Overpressure — Wood Frame Residential Buildings

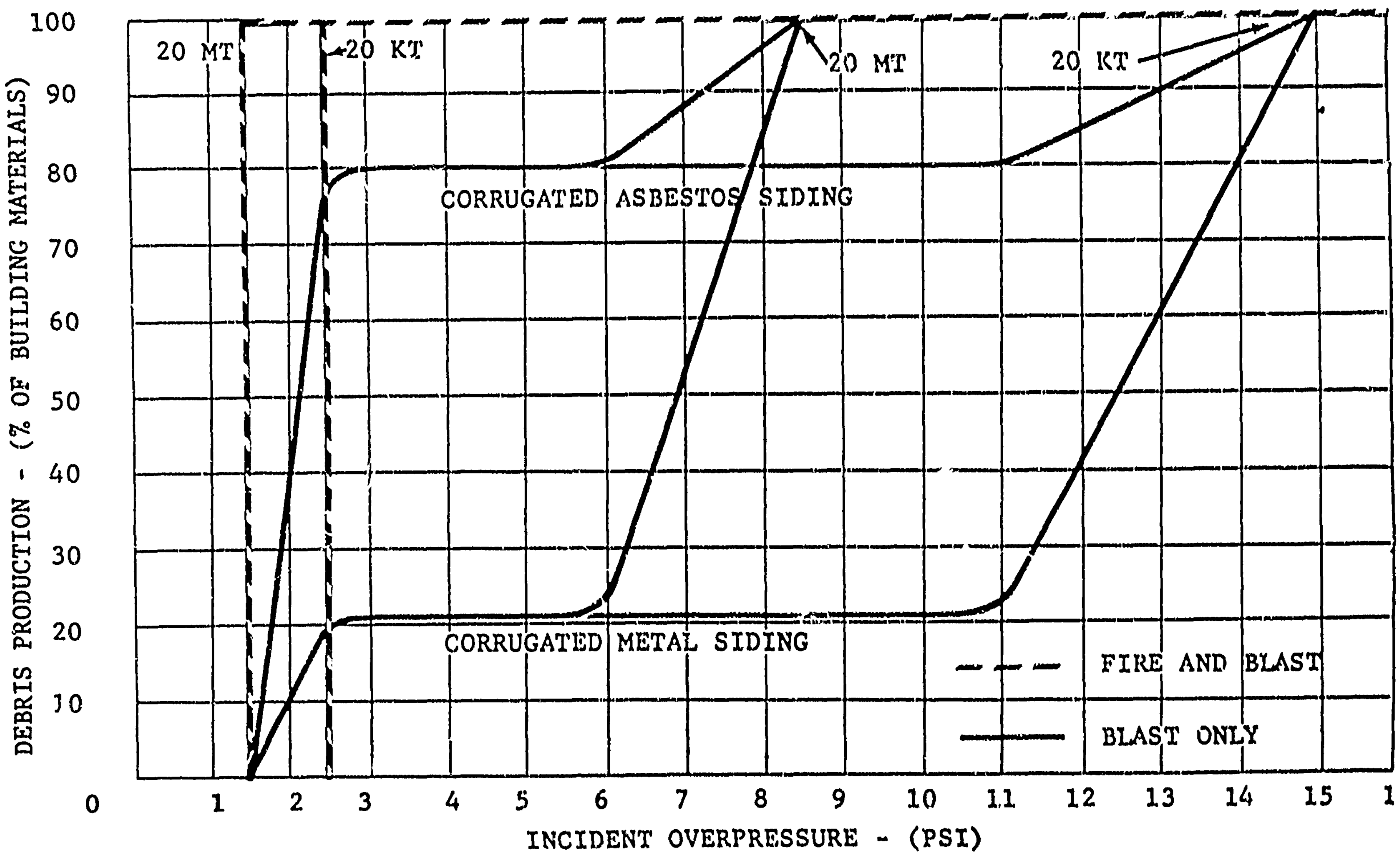

Fig. A-2. Coupled Fire and Blast Percent Debris vs Overpressure — Light Steel Frame Industrial Buildings

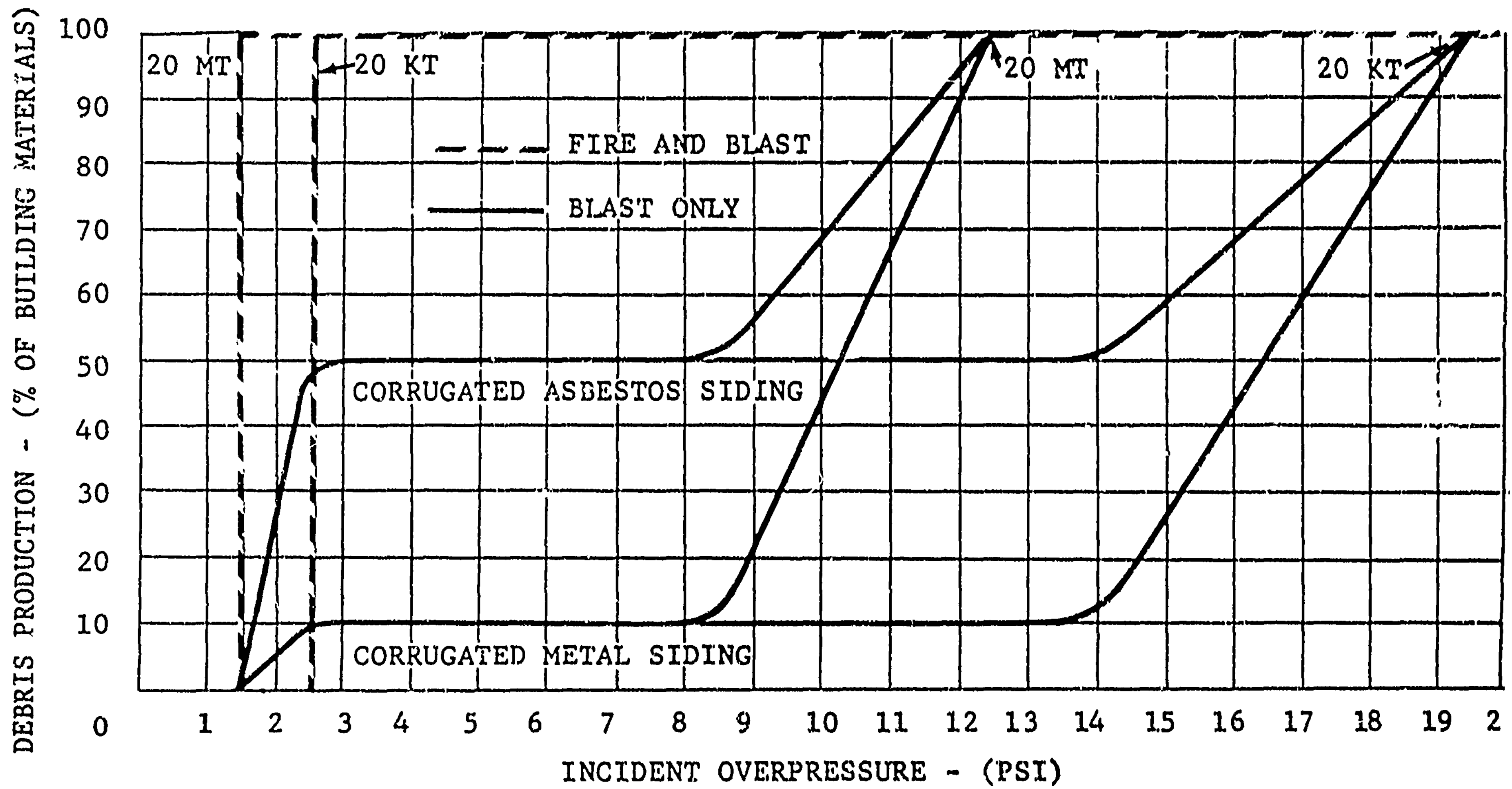

Fig. A-3. Coupled Fire and Blast Percent Debris vs Overpressure — Heavy Steel Frame Industrial Buildings

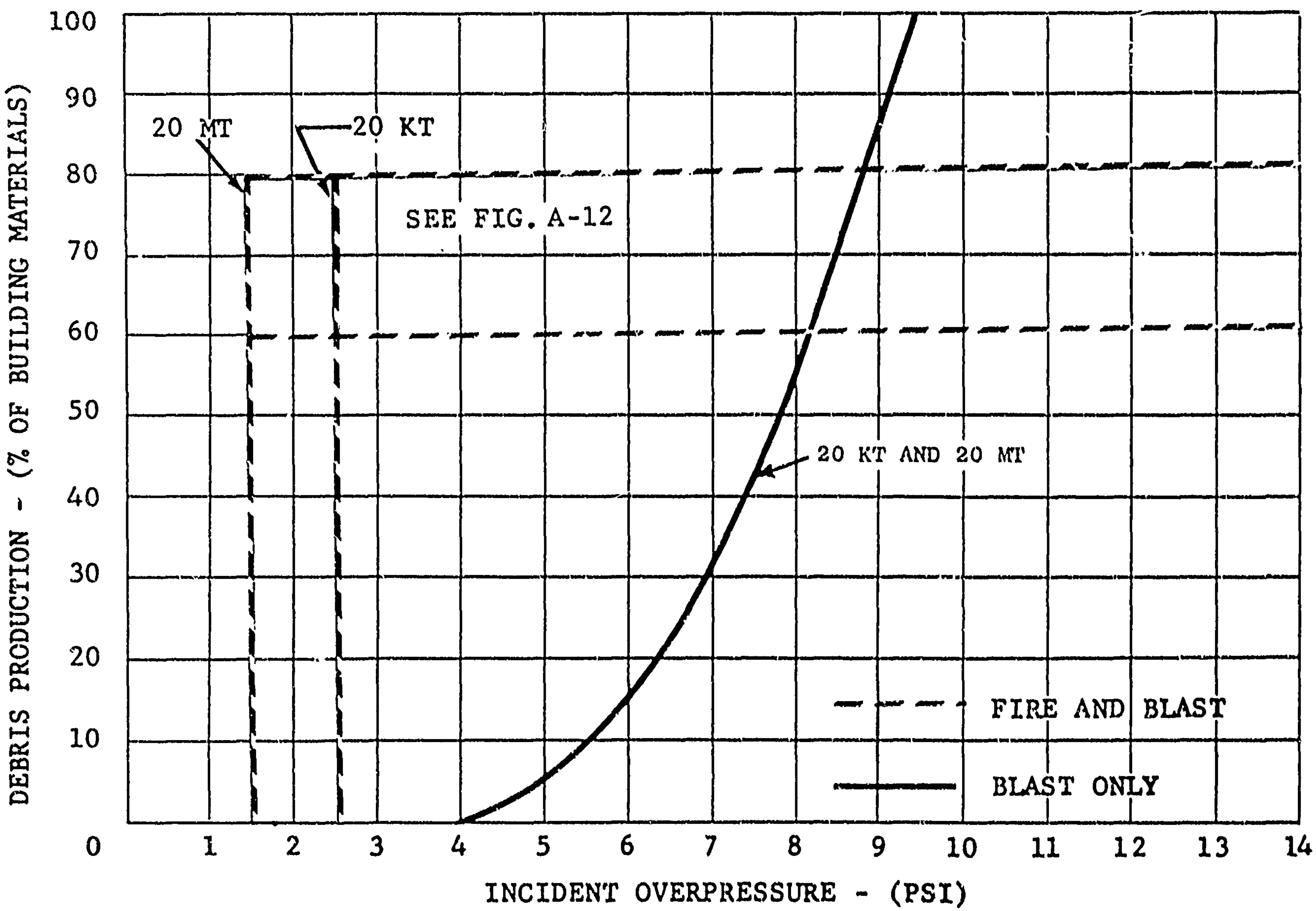

Fig. A-4. Coupled Fire and Blast Percent Debris vs Overpressure — Unreinforced Masonry Load-Bearing Wall Buildings

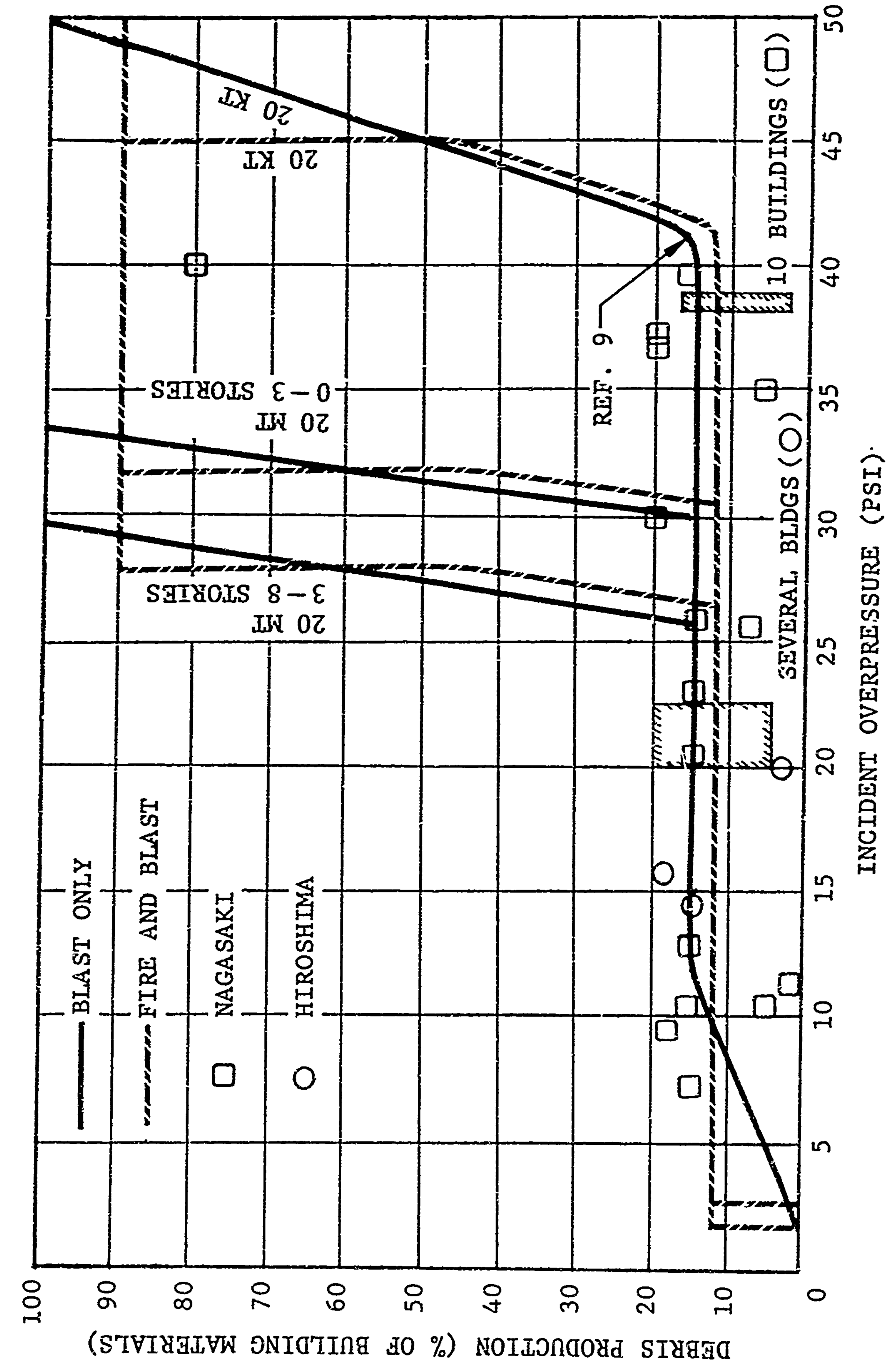

Fig. A-5. Coupled Fire and Blast Percent Debris vs Overpressure — Heavy Reinforced Concrete Multistory Shear-Wall Buildings With Light Interior Panels

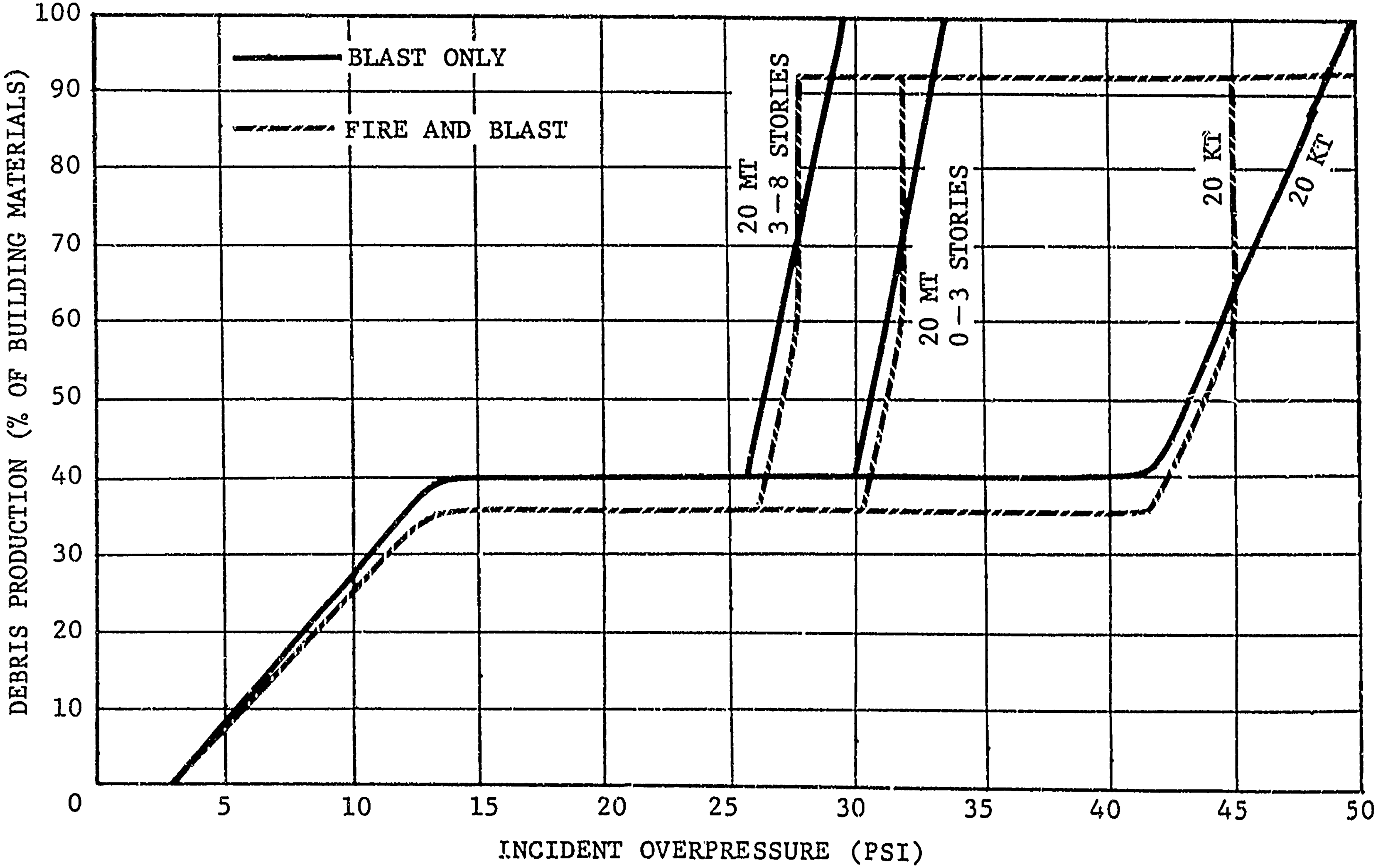

Fig. A-6. Coupled Fire and Blast Percent Debris vs Overpressure — Heavy Reinforced Concrete Multistory Shear-Wall Buildings With Masonry Interior Panels

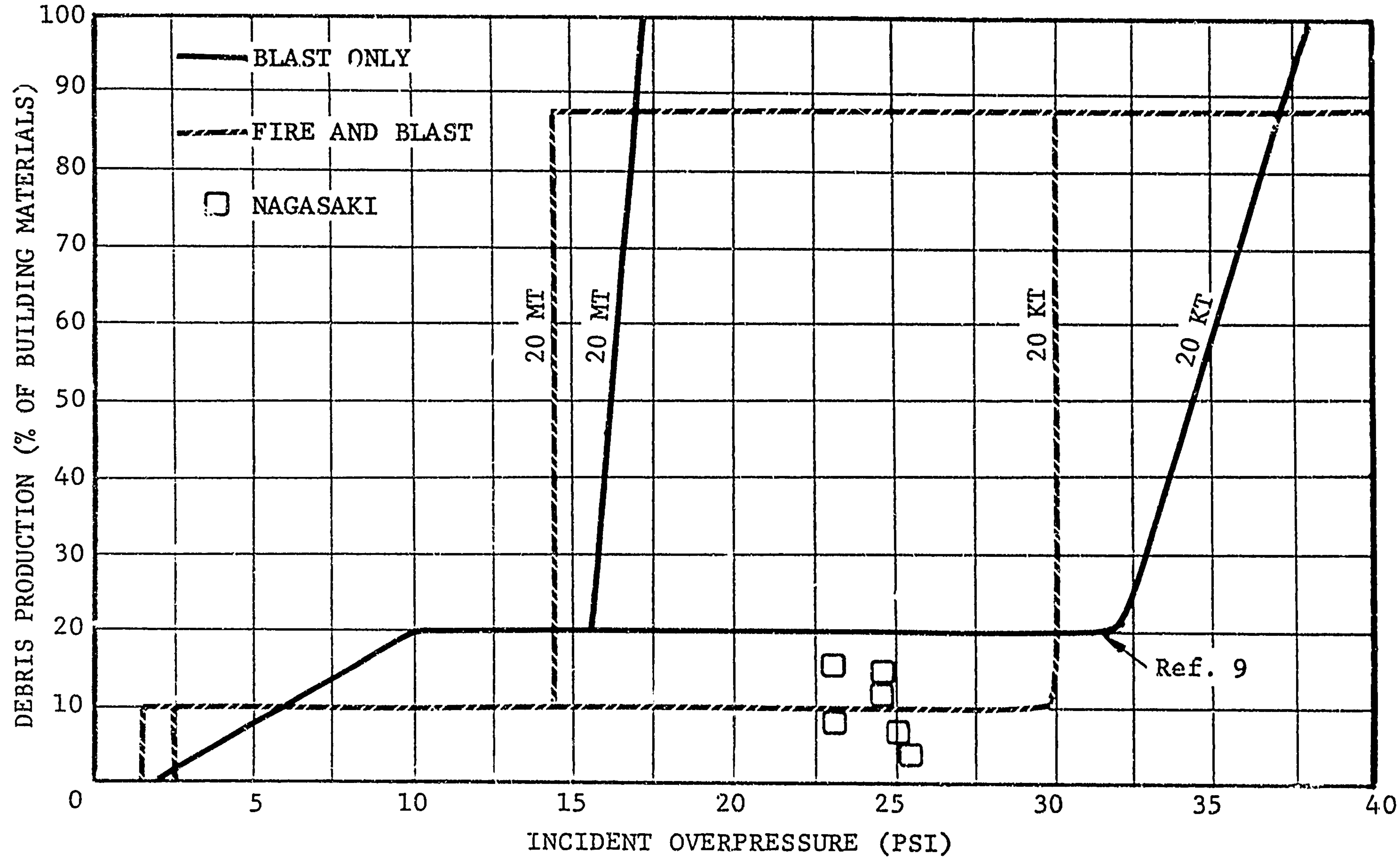

Fig. A-7. Coupled Fire and Blast Percent Debris vs Overpressure — Multistory Steel and Reinforced Concrete Frame Buildings With Earthquake Design and Light Panels

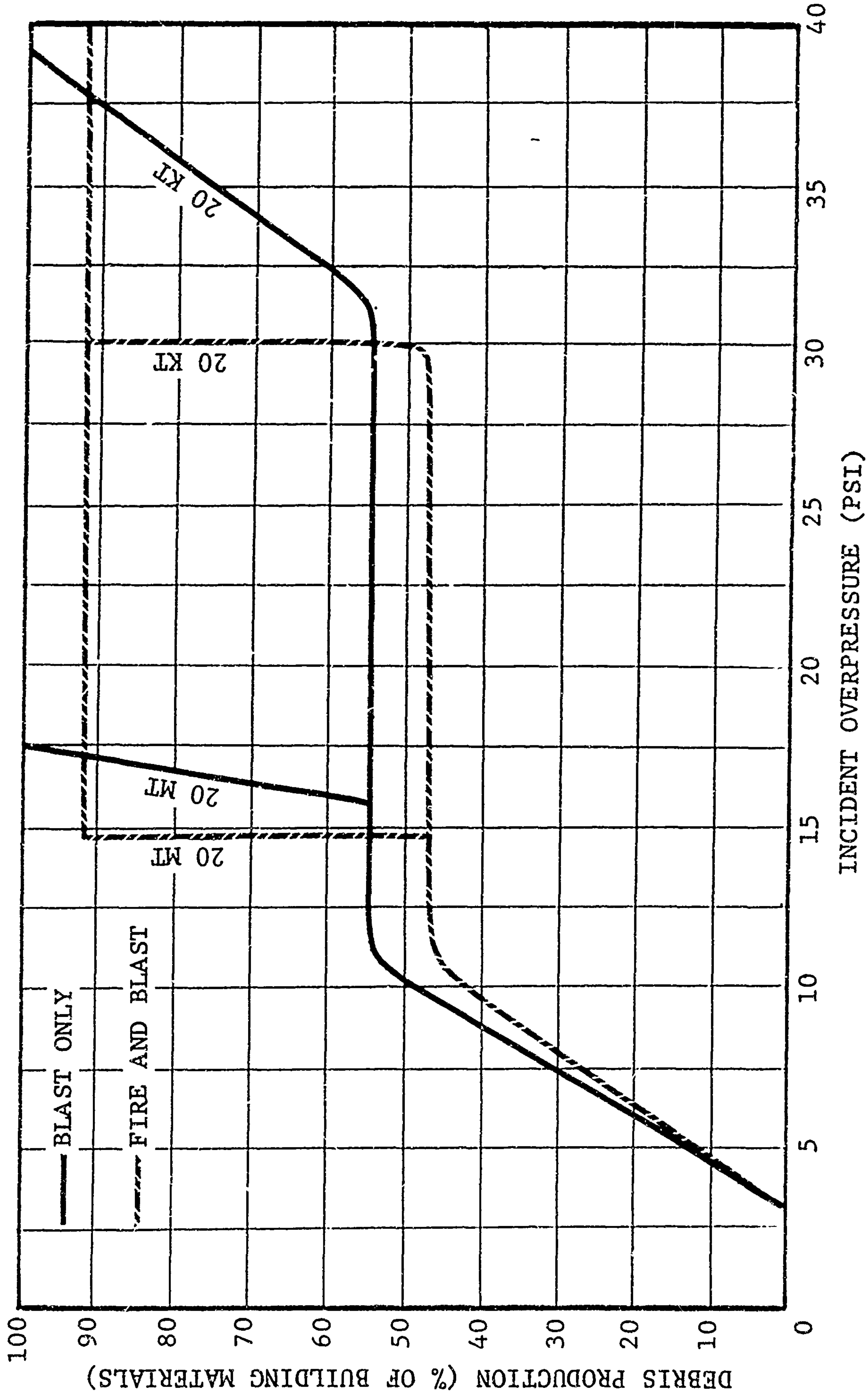

Fig. A-8. Coupled Fire and Blast Percent Debris vs Overpressure – Multistory Steel and Reinforced Concrete Frame Buildings With Earthquake Design and Masonry Panels

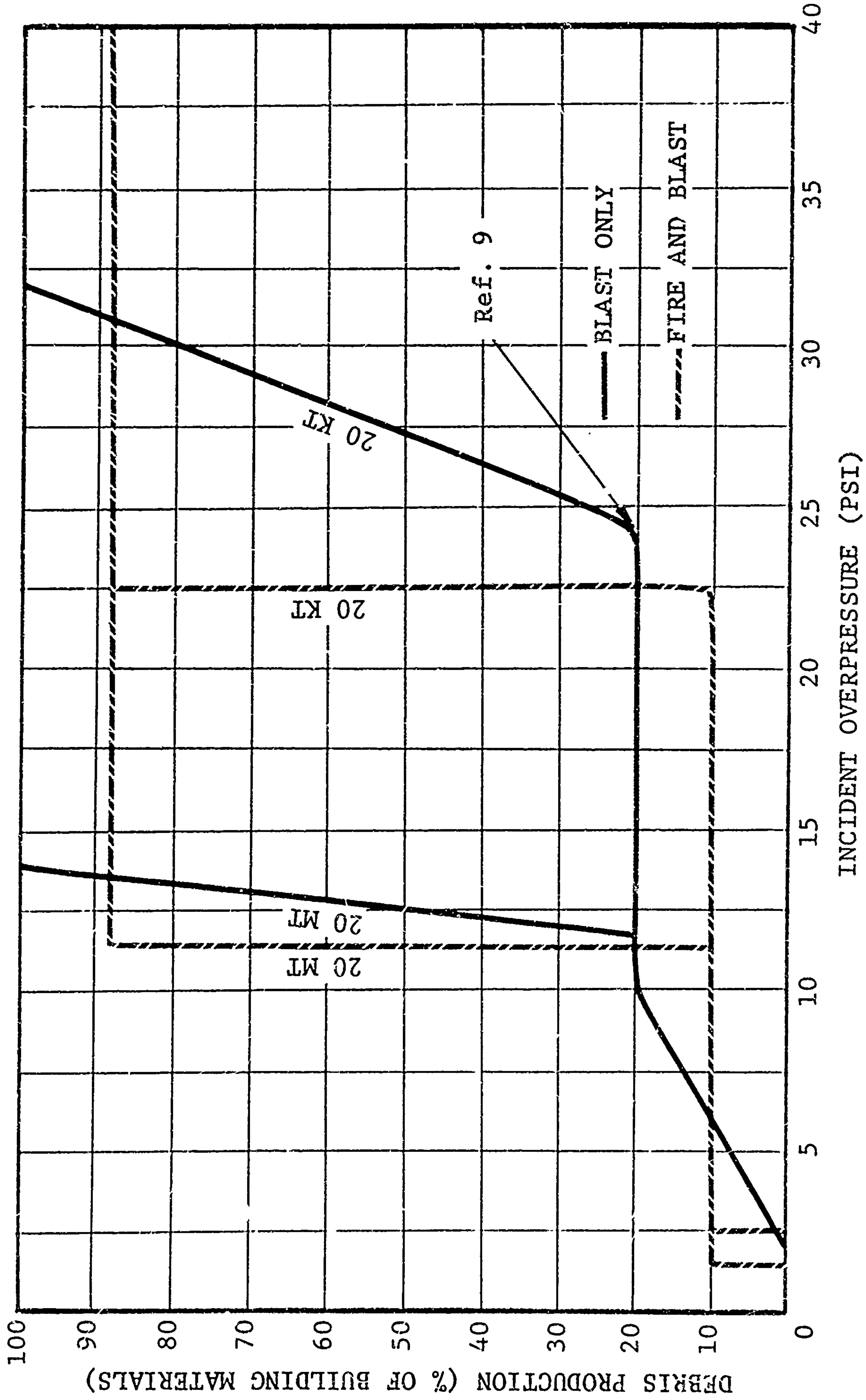

Fig. A-9. Coupled Fire and Blast Percent Debris vs Overpressure — Multistory Steel and Reinforced Concrete Frame Buildings — Non-earthquake Design With Light Panels

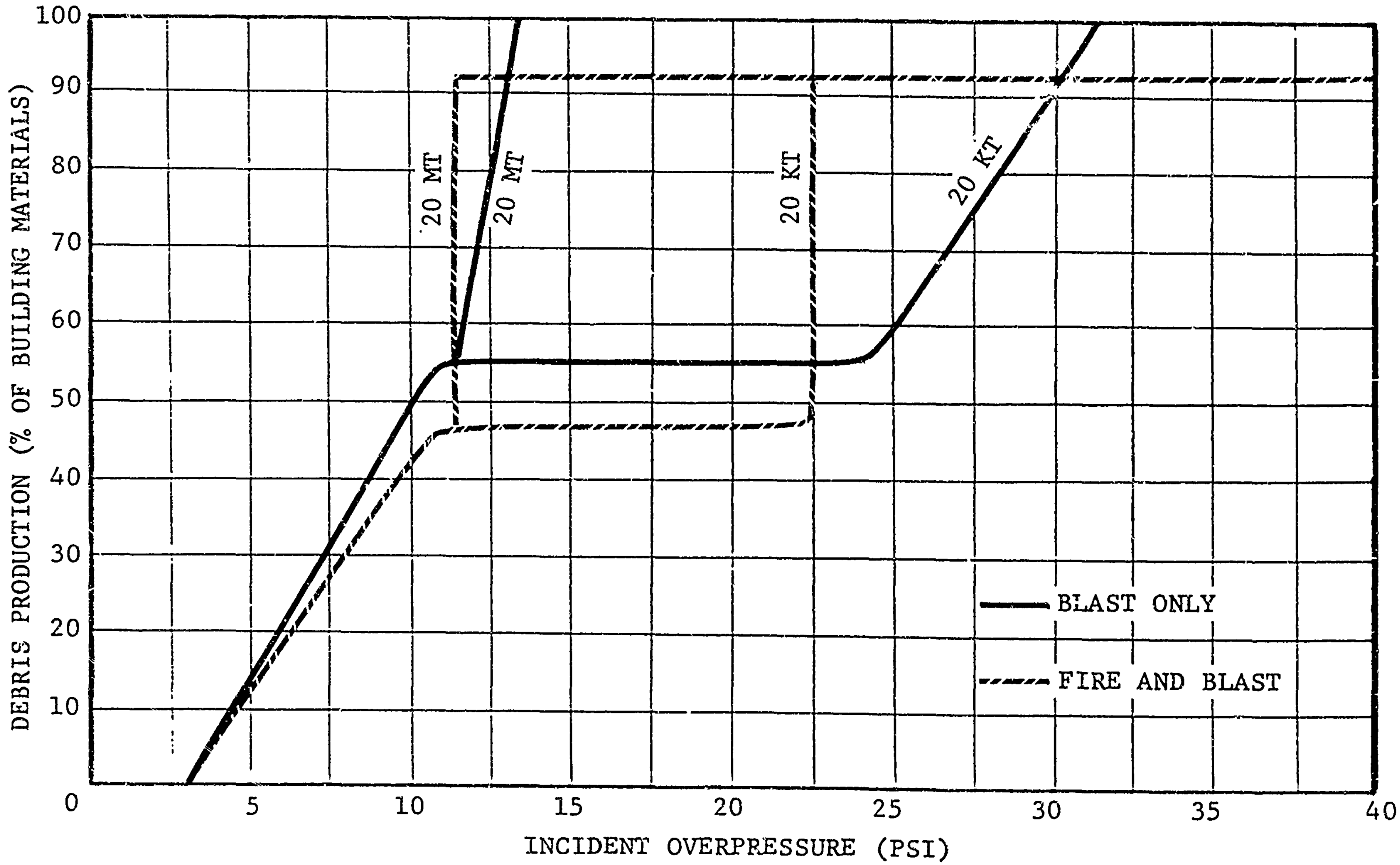

Fig. A-10. Coupled Fire and Blast Percent Debris vs Overpressure — Multistory Steel and Reinforced Concrete Frame Buildings — Non-earthquake Design With Masonry Panels

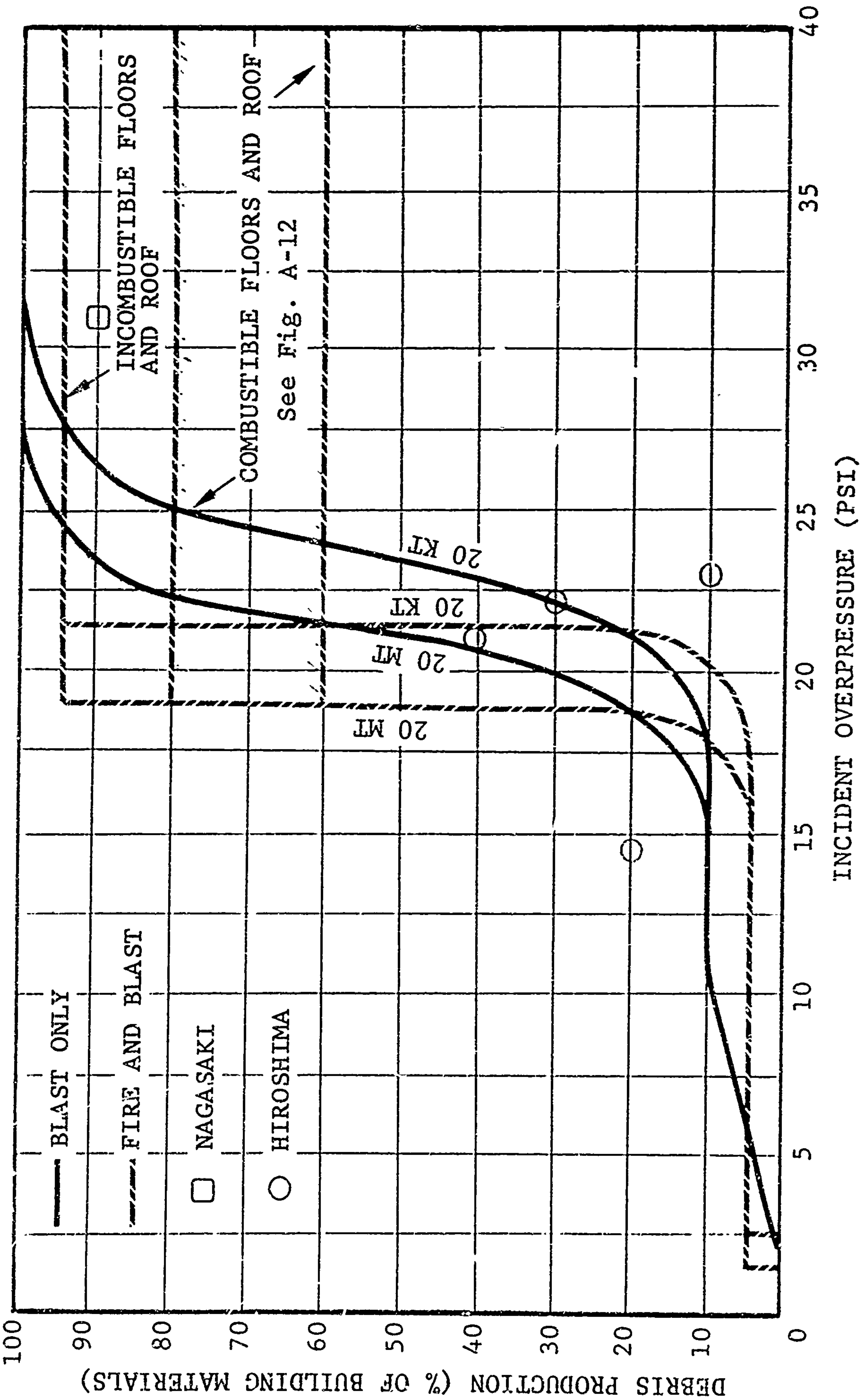

Fig. A-11. Coupled Fire and Blast Percent Debris vs Overpressure — Load-Bearing Masonry Building With Reinforcing or Reinforced Concrete Spandrels

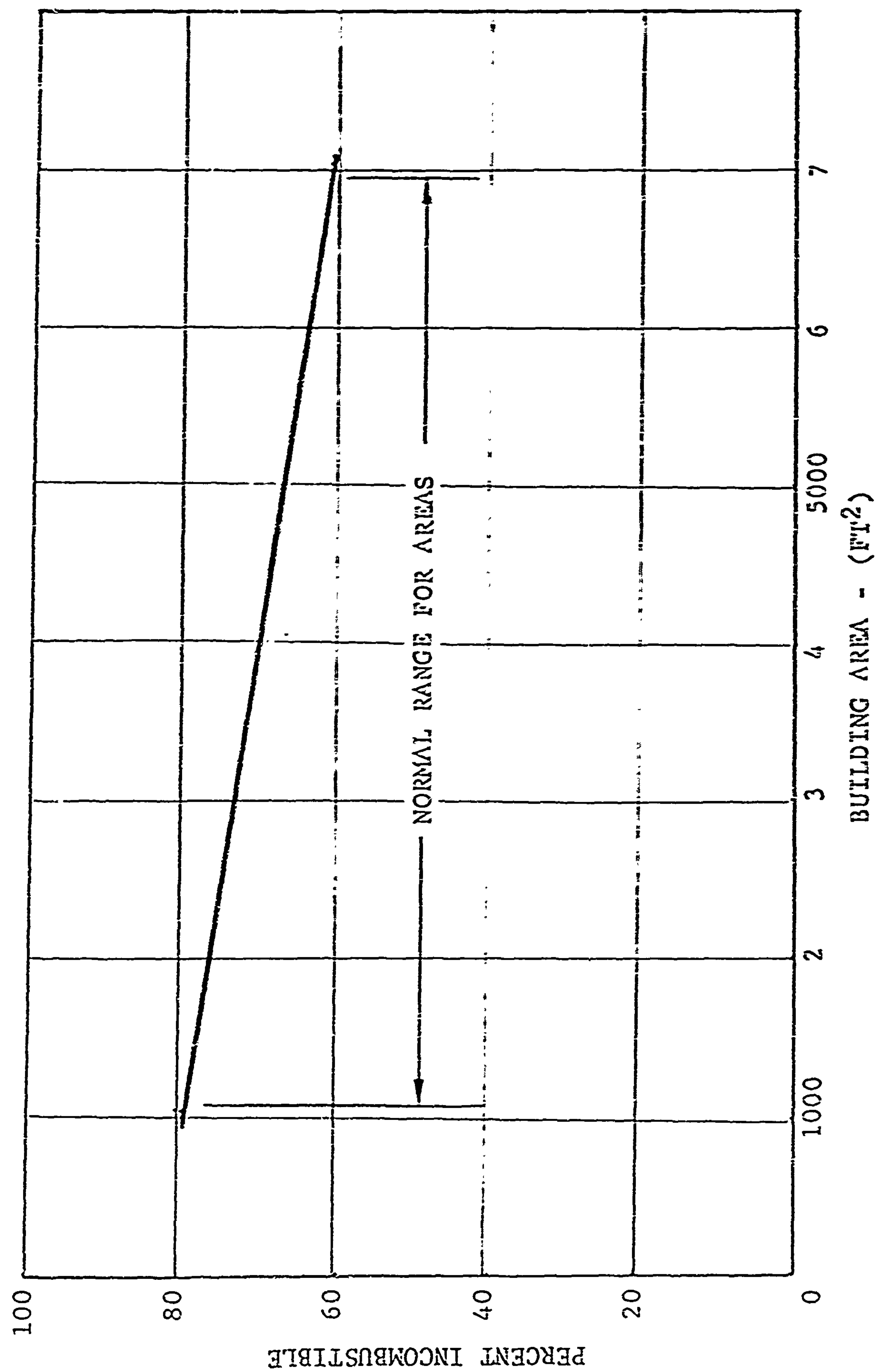

Fig. A-12. Percent Incombustible vs Plan Area — Load-Bearing Wall Masonry Buildings With All Wood Interior

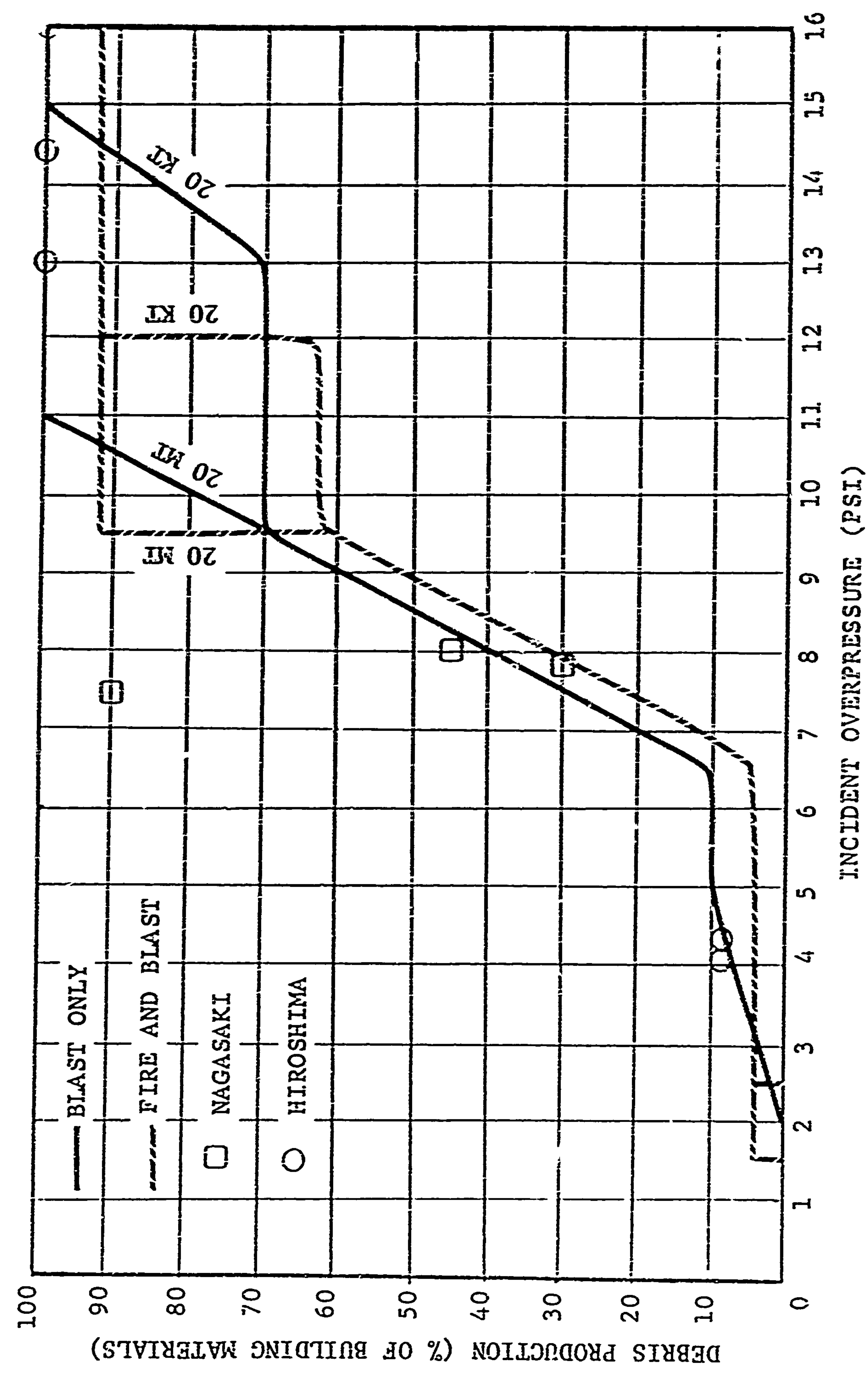

Fig. A-13. Coupled Fire and Blast Percent Debris vs Overpressure — Light Reinforced Concrete Shear-Wall Buildings With Concrete Roof and Light Interior Panels

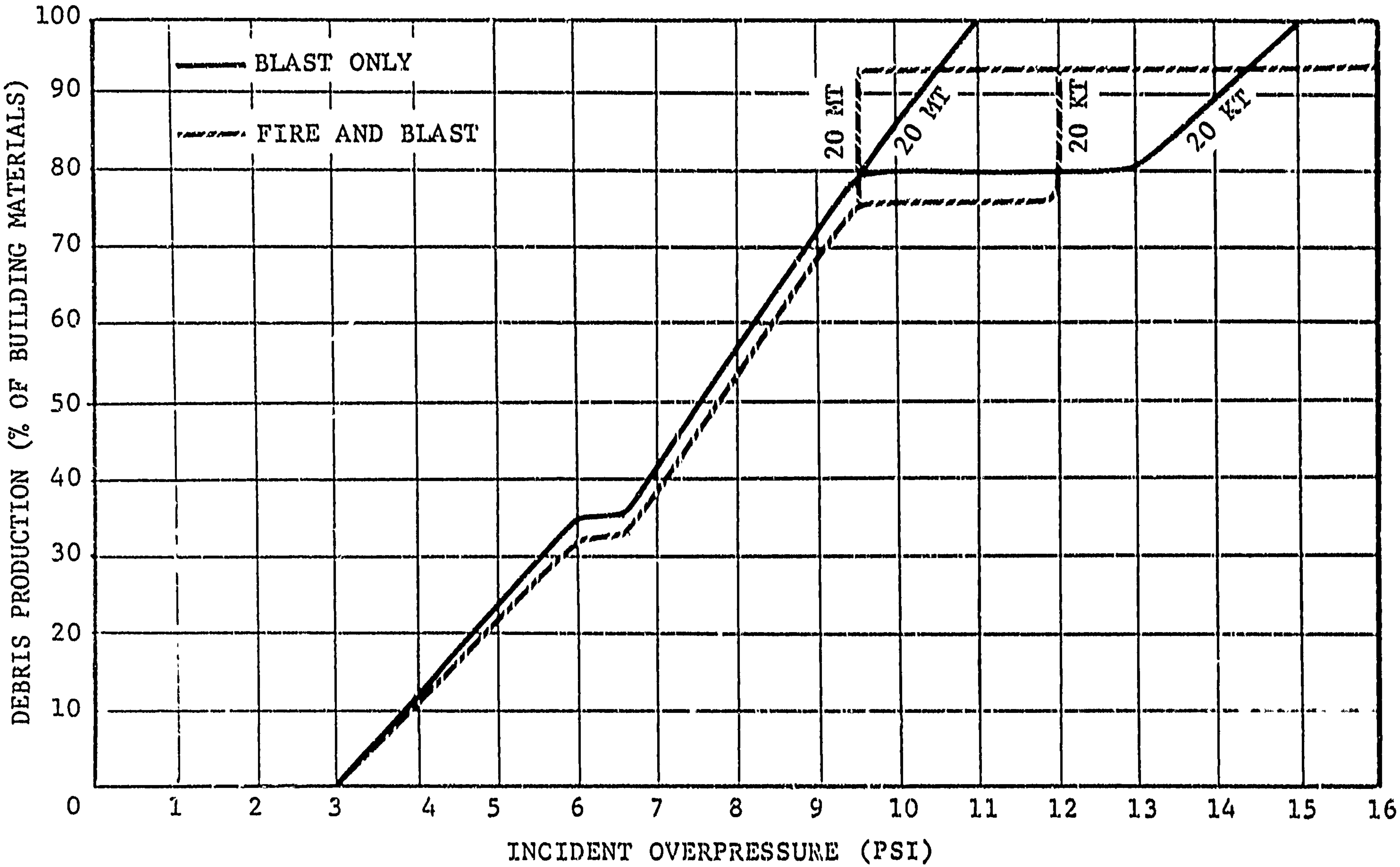

Fig. A-14. Coupled Fire and Blast Percent Debris vs Overpressure — Light Reinforced Concrete Shear-Wall Buildings With Concrete Roof and Masonry Interior Panels

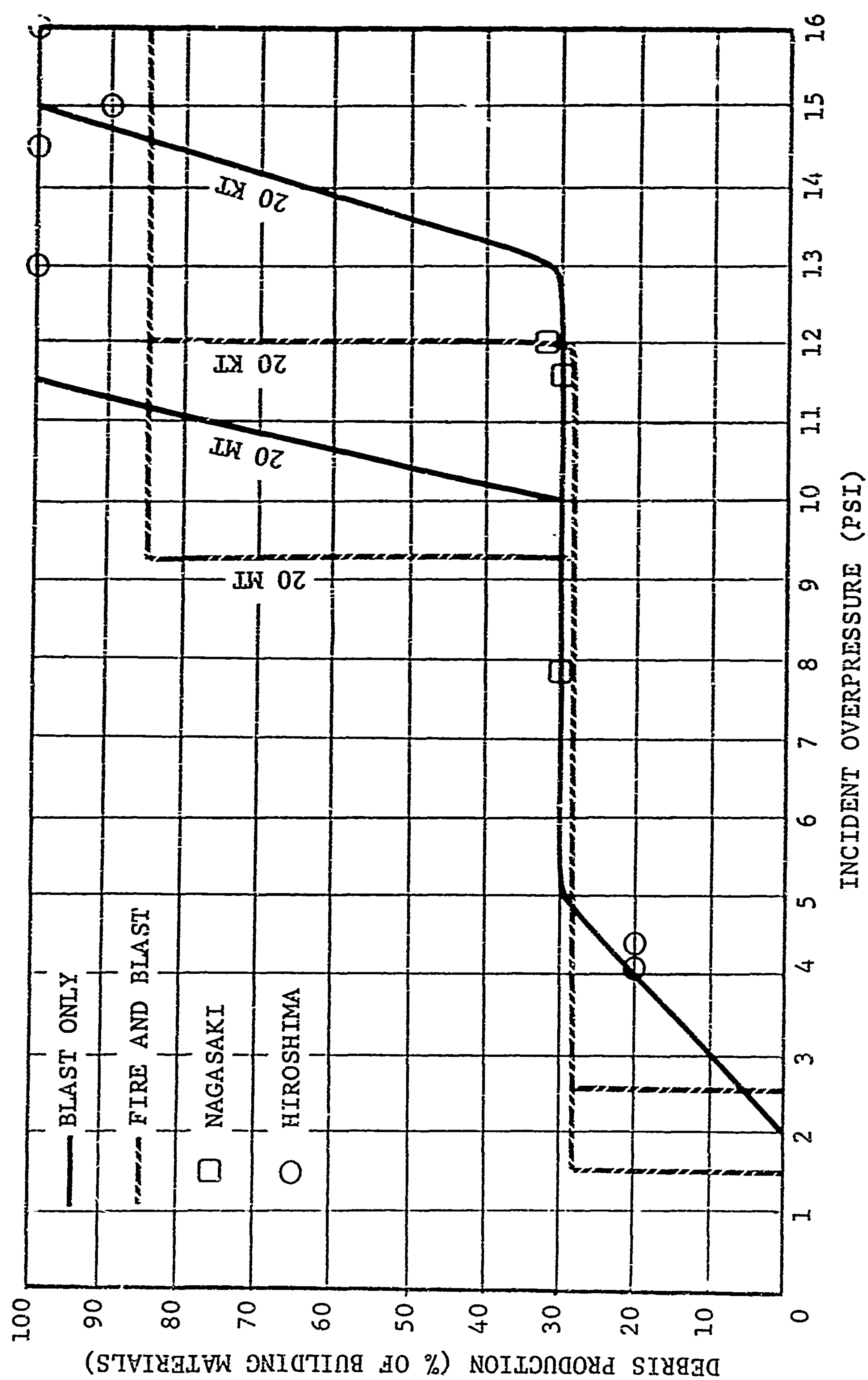

Fig. A-15. Coupled Fire and Blast Percent Debris vs Overpressure — Light Reinforced Concrete Shear-Wall Buildings With Mill-Type Roof and Light Interior Panels

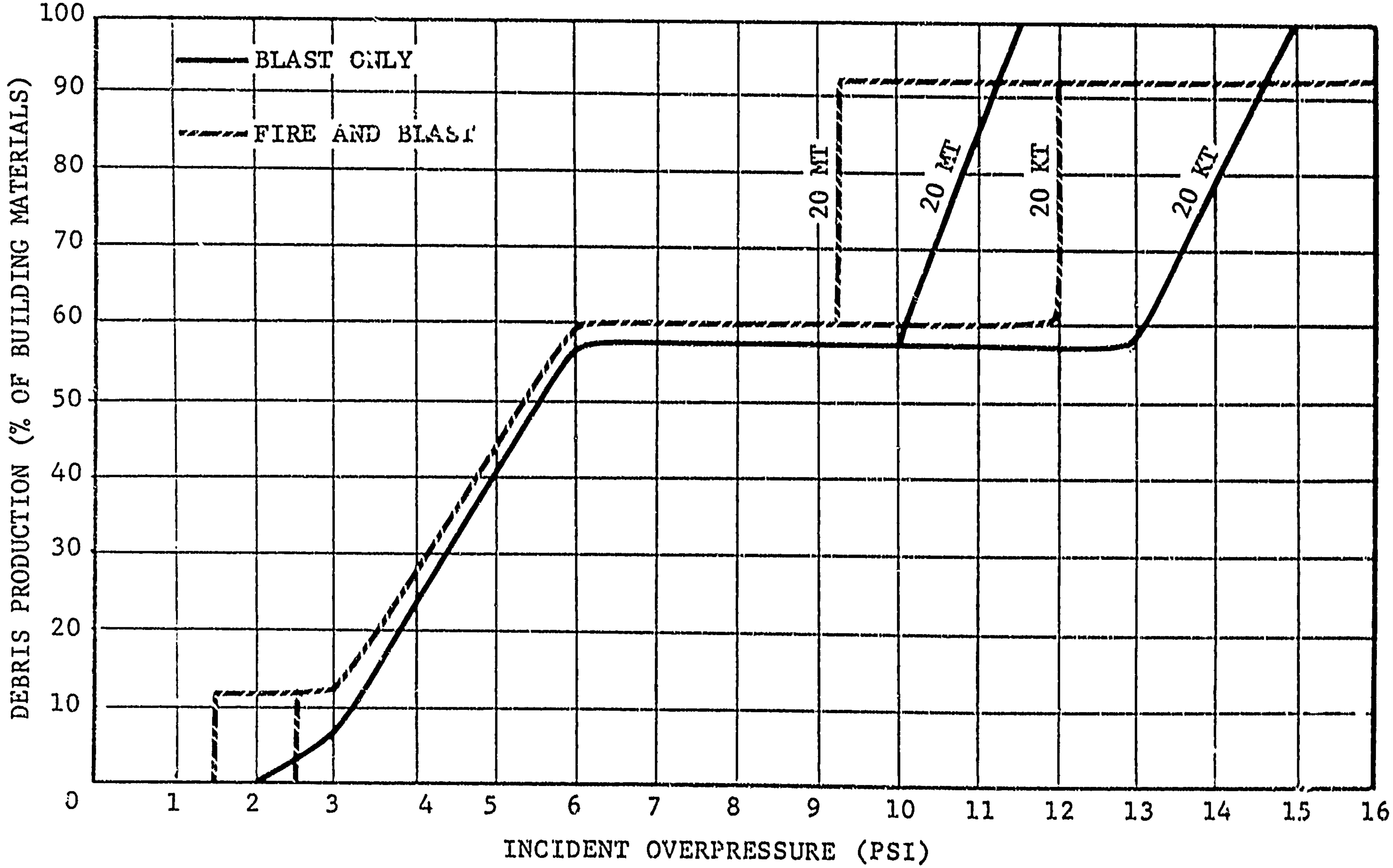

Fig. A-16. Coupled Fire and Blast Percent Debris vs Overpressure — Light Reinforced Concrete Shear-Wall Buildings With Mill-Type Roof and Masonry Interior Panels

Table A-1

FAILURE OVERPRESSURES FOR SMALL DRAG-SENSITIVE STRUCTURES AND ELEMENTS (20-kt and 20-Mt weapons)

Description	Overpressure at Failure (psi)	
	20 kt	20 Mt
Transmission Poles		
Radial Lines	8	3.8 (Ref. 12)
Transverse Lines	9	4.5 (Ref. 12)
Transmission Towers	10	5
Average Forest	8	3.8 (Ref. 12)
Stacks		
Reinforced Concrete:		
Over 4 ft diameter	25	11
4 ft and smaller diameter	15	7
Steel	5.5	2.6
Brick	5	4.5 (estimated)

Table A-2

BUILDING CONTENTS LOADS AND VOLUME FACTORS

Occupancy	PSF Combustible	PSF Total	Volume Factor K ($V = KA_pN$)* Total	After Fire
1. Apts. and Residential	3.5	5	0.625	0.02
2. Auditoriums and Churches	1	1.5	0.25	0.007
3. Garage				
a. Storage	1	15	0.75	0.30
b. Repair	1	11	0.55	0.20
4. Gymnasium	0.3	0.5	0.09	0.003
5. Hospitals	1.2	3	0.375	0.03
6. Hotels	4	5	0.625	0.013
7. Libraries	24	26	0.75	0.027
8. Manufacturing				
a. Comb. Mdse. fabrics, furniture	13.5	18	1.8	0.07
b. Incombustible	1	11	0.55	0.20
9. Offices	7	12	1.2	0.10
10. Printing Plant				
a. Newspaper	10	23	0.9	0.20
b. Books	50	60	1.7	0.13
11. Schools	9.5	11	1.6	0.02
12. Storage				
a. Gen. Mdse.	14	35	6	0.3
b. Special	-	**		
13. Stores				
a. Retail Dept.	7.5	12	2	0.10
b. Wholesale	10	16	2.7	0.12
14. Restaurant	2	3.5	0.6	0.02

* V = Volume in cubic feet
A_p = Plan area in square feet
N = Number of stories

** 25 percent of design load

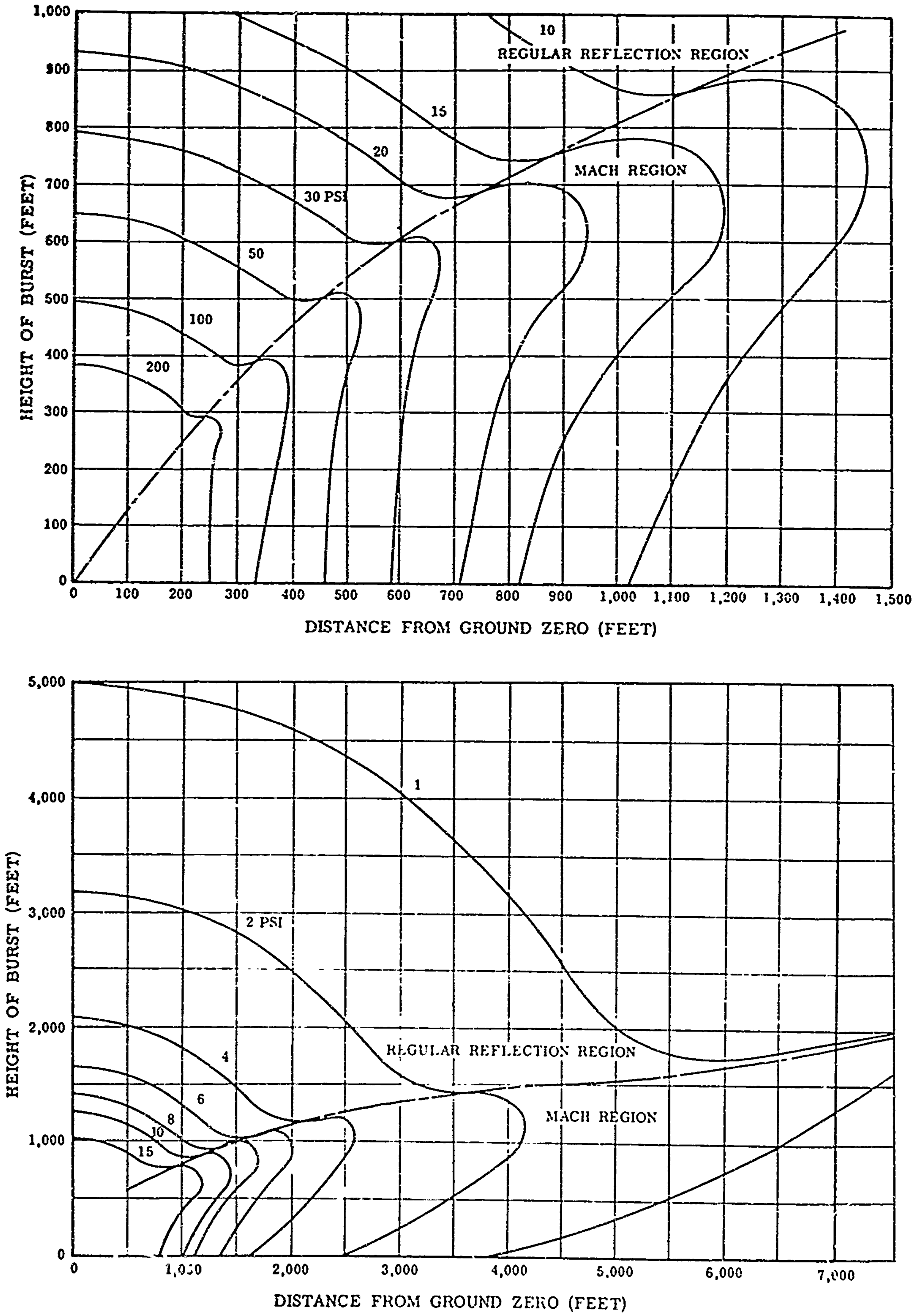

Fig. A-17. Peak Overpressures on the Ground for a 1-kt Burst

TIME-SAVING IMPROVEMENTS

In working with and operating the Debris Model, certain techniques have been developed which increase its versatility and improve its operational efficiency. These include simplified means for estimating structural volumes and for calculating building areas. The techniques are described below.

Structural Volumes

To develop the debris charts it was necessary to calculate the volume of structural material contained in the various types of structures in order to calculate percentages of total structural debris contributed by each building element. Structural volumes must also be calculated when the model (with charts) is used to make debris predictions for specific buildings; and in applying the model to specific complexes, such calculations were made. As a by-product, much information has been assembled on volumes of structural material contained in the various types of buildings.

To avoid the need to make similar detailed calculations (which are laborious, tedious, and time consuming) in the future, it was deemed highly desirable to develop simplified means for estimating structural material volumes, utilizing building type and physical dimensions (both of which are readily determined) as controlling parameters.

The controlling dimensional parameters were first isolated for each building type. Empirical formulae relating these parameters to material volumes were then derived utilizing constants that reflect mean or average values (deviations of 10 percent are common and 15 percent rare).* These formulae (with legend of terms) are presented in Table A-3. The percentage of incombustible materials is also identified.

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* Should grossly abnormal structures be encountered, they should be individually treated in detail.

Table A-3

STRUCTURE VOLUME VS BUILDING TYPE

Building Type	Volume Formula*	Percent Incombustible
1. Wood Frame Residential		
a. 1st floor slab on ground	$[0.55 + (N-1)(0.525)]A_p$	42 - S&P 28 - W&P
b. 1st floor on std. joists	$[0.7 + (N-1)(0.525)]A_p$	2 - W
2. Steel Frame Industrial		
a. Light W/CI sheathing	$0.02\ A_p$	0
W/CA sheathing	$0.087\ A_p$	0
b. Heavy W/CI sheathing	$0.037\ A_p$	0
W/CA sheathing	$0.095\ A_p$	0
3. Load-Bearing Masonry With or Without Reinforcing — Combustible Interior Framing	$0.12\ V_c$	$80 - \frac{1}{300}(A_p - 1000)$ $1000 < A_p < 7000$
4. Heavy Reinforced Concrete Shear-Wall		
a. W/lt. interior panels	$0.07\ V_c$	90
b. W/masonry interior panels	$0.12\ V_c$	93
5. Multistory Steel and Reinforced Concrete Frame With Earthquake Design		
a. W/lt. interior panels	$0.07\ V_c$	88
b. W/masonry interior panels	$0.11\ V_c$	92
6. Multistory Steel and Reinforced Concrete Frame (Non-earthquake design)		
a. W/lt. interior panels	$0.063\ V_c$	88
b. W/masonry interior panels	$0.10\ V_c$	92

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* These formulae reflect solid volume of material (i.e., no voids—voids ratio = 0). The voids ratio (usually taken as unity) is best applied after summation of contributory volumes. This minimizes the number of calculations required for making debris volume or debris depth estimates.

Table A-3 (Cont.)

Building Type	Volume Formula	Percent Incombustible
7. Light Reinforced Concrete Shear-Wall (single story)		
a. Concrete roof w/lt. interior panels	$0.07\ V_c$	92
b. Concrete roof w/masonry interior panels	$0.075\ V_c$	94
c. Mill roof w/lt. int. panels	$0.037\ V_c$	85
d. Mill roof w/masonry interior panels	$0.05\ V_c$	92

LEGEND:

V_c	contained volume
A_p	plan area
N	number of stories
S&P	stucco exterior plaster interior
W&P	wood exterior plaster interior
W	all wood
CI	corrugated iron
CA	corrugated asbestos

0).

Building Area Chart

It can be noted in Table A-3 that the plan area (A_p) or the total contained volume (V_c) of the building appears in all formulae. To calculate either requires that the plan dimensions of a building, i.e., its length and width (usually scaled from Sanborn maps) be multiplied together. The basic operation requires reading and recording two numbers, multiplying them together (either by hand, slide rule, or desk calculator), and recording the product. This procedure is very time consuming and is greatly facilitated by use of the direct-reading area chart similar to that illustrated in Fig. A-18, in which the reading and multiplying steps have been combined. With such a chart, finding the area of a building is reduced to taking and recording only one reading for each building. This chart should be printed on transparent material to make it easier to use.

Since Sanborn maps are usually drawn to scale of 1 in. = 25 ft, 50 ft, or 100 ft, preparation of an original area chart for the 1 in. = 50 ft scale, having it photographically halved or doubled in scale, and having transparencies printed would provide charts for all three scales.

To use this type of chart, the origin "0" is placed over one corner of the building plan (on the Sanborn map) and the axes aligned with the principal axes of the building. The area is then read by visually interpolating between the isoarea curves bracketing the diagonally opposite corner of the building.

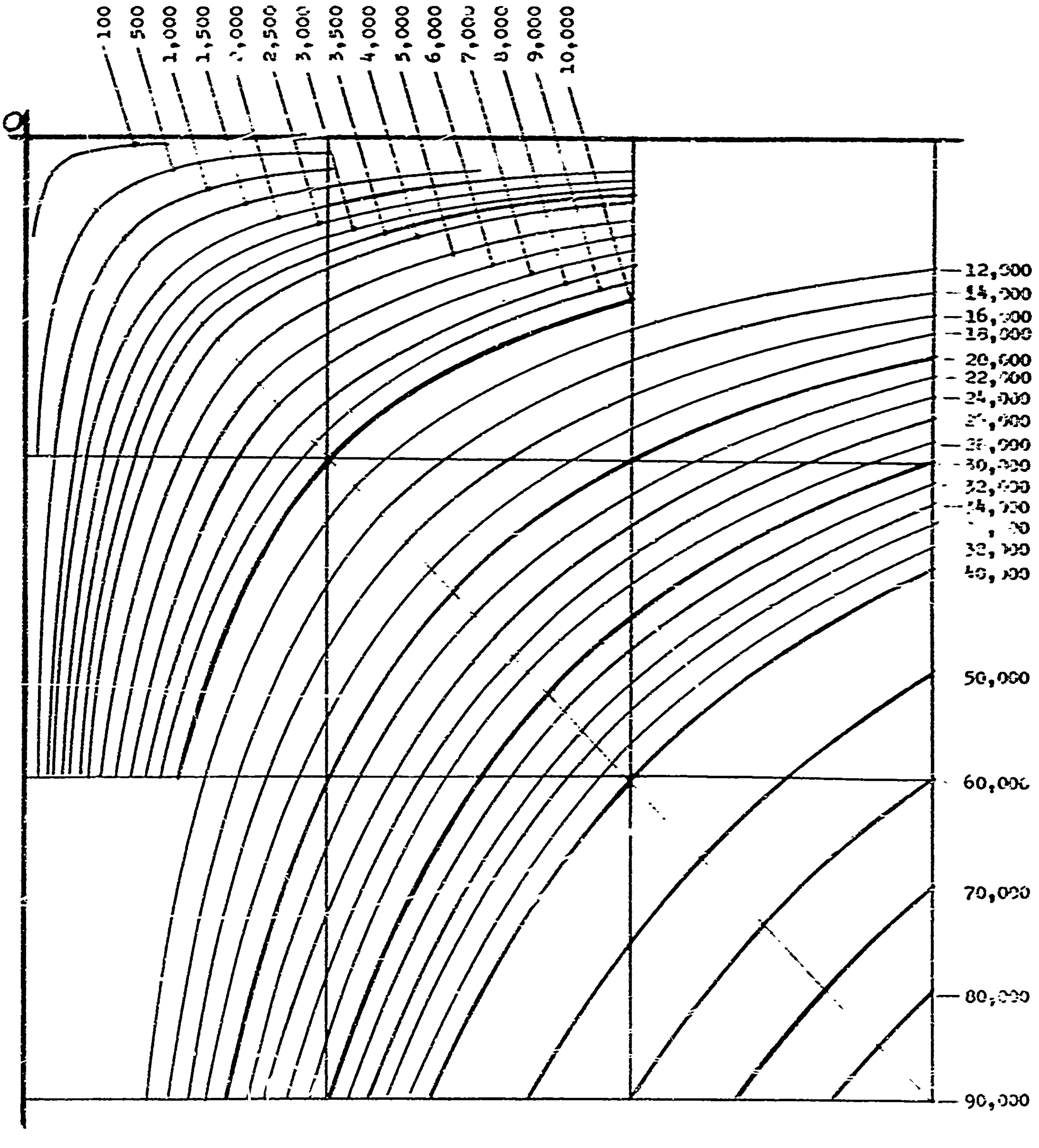


Fig. A-18. Direct-Reading Area Chart Drawn for Map Scale 1 in. Equals 50 ft

Appendix B

SAMPLE DATA SHEETS AND DEBRIS CONTOUR MAPS

BY______ DATE______

CHKD. BY______ DATE______

SUBJECT DETROIT
Sheet 2 Volume I
TD Cross Street Michigan & Gris.

STRUCTURAL DEBRIS - CU. FT.

Address	Use	Type	Stories	Height FT	Plan Area SQ FT	Without Fire	With Fire
Dime Bldg.	9	6b	23	285	18,500	(0.1)(285)(18500) = 527,000	(0.92)(527000) = 485,
Fed. Res. Bank	9	6b	5	50	19,000	(0.1)(50)(19000) = 95,000	(0.92)(95000) = 87,300
Fed. Res Bank	9	6b	4	60	7,500	(0.1)(60)(7500) = 45,000	(0.92)(45000) = 41,3
755 Griswold	9	6a	7	89	5,000	(0.063)(89)(5000) = 28,050	(0.88)(28,050) = 24,7
751 Griswold	9	6a	5	65	4,700	(0.063)(65)(4700) = 19,250	(0.88)(19,250) = 16,94
Can. Natl GT	9	6b	10	130	12,500	(0.1)(130)(12500) = 162,400	(0.92)(162400) = 149,
141 Lafayette	14	3	2	24	5,800	(0.12)(24)(5800) = 16,720	(0.8)(16720) = 13,380
101 Michigan	13a	3	5	58	1,170	(0.12)(58)(1170) = 8,150	(0.8)(8150) = 6,520
117 Michigan	13a	3	3	33	1,710	(0.12)(33)(1710) = 6,780	(0.8)(6780) = 5,420
127 Michigan	13a	3	3	45	2,480	(0.12)(45)(2480) = 13,400	(0.8)(13,400) = 10,720
Lafayette Bldg	9	6b	14	170	9,850	(0.1)(170)(9850) = 167,400	(0.92)(167400) = 153,0
201 Michigan	9	6a	3	48	6,600	(0.063)(48)(6600) = 19,960	(0.88)(19,960) = 17,55
1010 Wash. Blvd	9	3	1	10	900	(0.12)(10)(900) = 1,080	(0.9)(1080) = 970
238 Lafayette	14	3	1	12	700	(0.12)(12)(700) = 1,050	(0.8)(1050) = 840

A

SUBJECT DETROIT
Sheet 2 Volume I
ID Cross Street Michigan & Griswold

SHEET NO.____OF____
JOB NO.____
5 PSI

AREA = (380 x 300) + (325 x 425) + 84,100 +
= 114,000 + 138,000 + 84,100 = 336

	UCTURAL DEBRIS - CU. FT. With Fire	CONTENTS - CU. FT. Without Fire	CONTENTS - CU. FT. With Fire
0	(0.92)(527000) = 485,000	(1.2)(18500)(23) = 510,000	(0.1)(23)(18500) = 42,600
	(0.92)(95000) = 87,300	(1.2)(13000)(5) = 114,000	(0.1)(5)(13000) = 9,500
	(0.92)(45000) = 41,300	(1.2)(4)(7500) = 36,000	(0.1)(4)(7500) = 3,000
0	(0.88)(28,050) = 24,700	(1.2)(7)(5000) = 42,000	(0.1)(7)(5000) = 3500
50	(0.88)(19,250) = 16,940	(1.2)(5)(4700) = 28,200	(0.1)(5)(4700) = 2,350
0	(0.92)(162400) = 149,400	(1.2)(10)(12500) = 150,000	(0.1)(10)(12500) = 12,500
	(0.8)(16720) = 13,380	(0.6)(5800)(2) = 6960	(0.02)(2)(5800) = 230
	(0.8)(8150) = 6,520	(2)(1170)(5) = 11,700	(0.1)(1170)(5) = 590
	(0.8)(6780) = 5,420	(2)(1710)(3) = 10,260	(0.1)(1710)(3) = 510
	(0.8)(13,400) = 10,720	(2)(3)(2480) = 14,880	(0.1)(3)(2480) = 740
	(0.92)(167400) = 153,000	(1.2)(9850)(14) = 165,400	(0.1)(14)(9850) = 13,790
60	(0.88)(19,960) = 17,550	(1.2)(6600)(3) = 23800	(0.1)(3)(6600) = 1,980
	(0.9)(1080) = 970	(1.2)(900)(1) = 1080	(0.1)(1)(900) = 90
	(0.8)(1050) = 840	(0.6)(700) = 420	(0.02)(1)(700) = 20.

B

Fig. B-

ft | SHEET NO.____ OF____
JOB NO.____
36 Griswold | 5 PSI

AREA = (380 × 300) + (325 × 425) + 84,100 from Sheet 6, Volume 1
= 114,000 + 138,000 + 84,100 = 336,100 Sq. Ft.

CONTENTS - CU. FT.

	Without Fire	With Fire
5000	(1.2)(18500)(23) = 510,000	(0.1)(23)(18500) = 42,600
	(1.2)(19000)(5) = 114,000	(0.1)(5)(19000) = 9500
'00	(1.2)(4)(7500) = 36,000	(0.1)(4)(7500) = 3000
800	(1.2)(7)(5000) = 42,000	(0.1)(7)(5000) = 3500
10	(1.2)(5)(4700) = 28,200	(0.1)(5)(4700) = 2,350
,400	(1.2)(10)(12500) = 150,000	(0.1)(10)(12500) = 12,500
	(0.6)(5800)(2) = 6960	(0.02)(2)(5800) = 230
	(2)(1170)(5) = 11,700	(0.1)(1170)(5) = 590
	(2)(1710)(3) = 10,260	(0.1)(1710)(3) = 510
7	(2)(3)(2480) = 14,880	(0.1)(3)(2480) = 740
900	(1.2)(9850)(14) = 165,400	(0.1)(14)(9850) = 13,790
50	(1.2)(6600)(3) = 23800	(0.1)(3)(6600) = 1980
	(1.2)(900)(1) = 1080	(0.1)(1)(900) = 90
	(0.6)(700) = 420	(0.02)(1)(700) = 20.

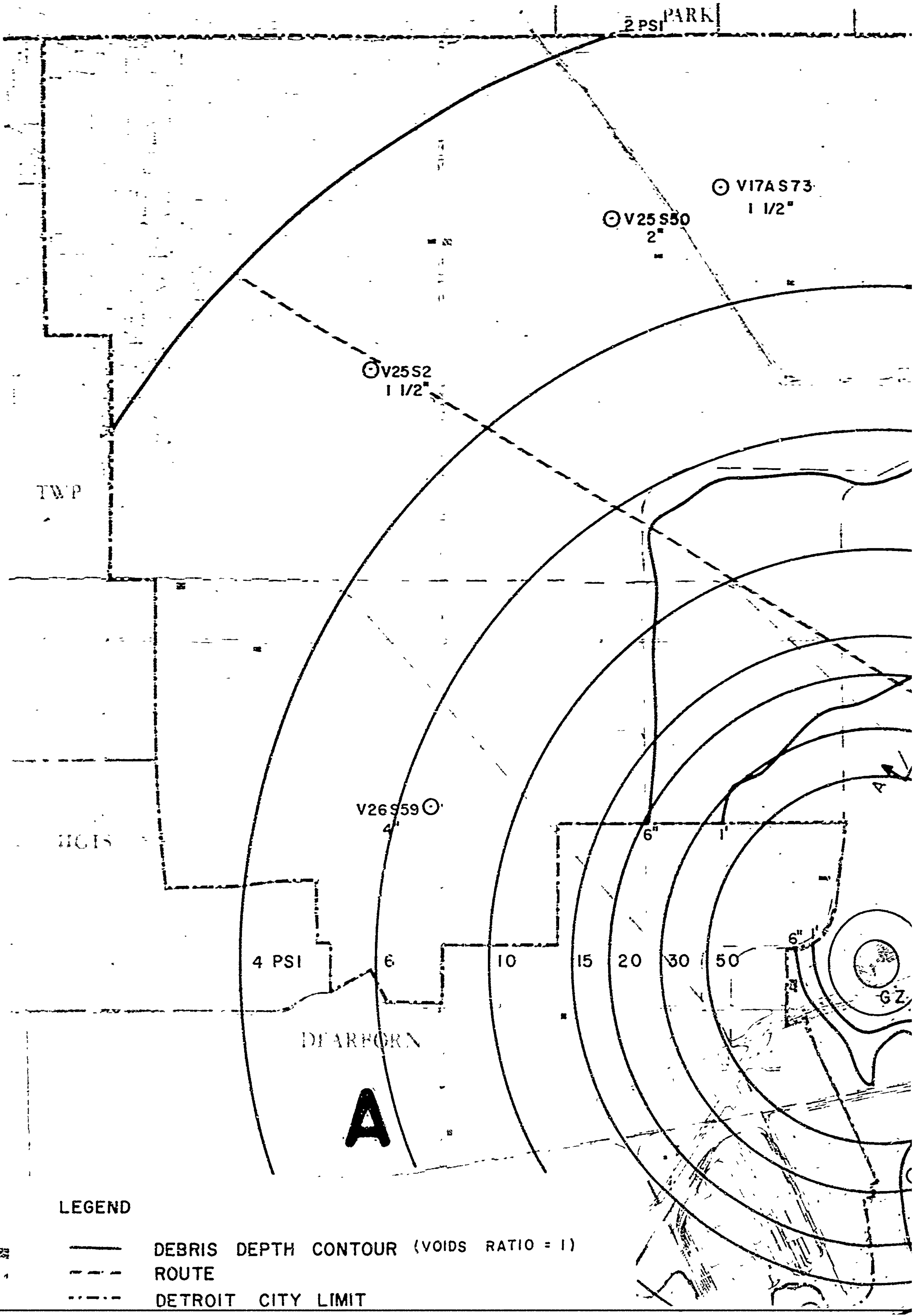
STREET

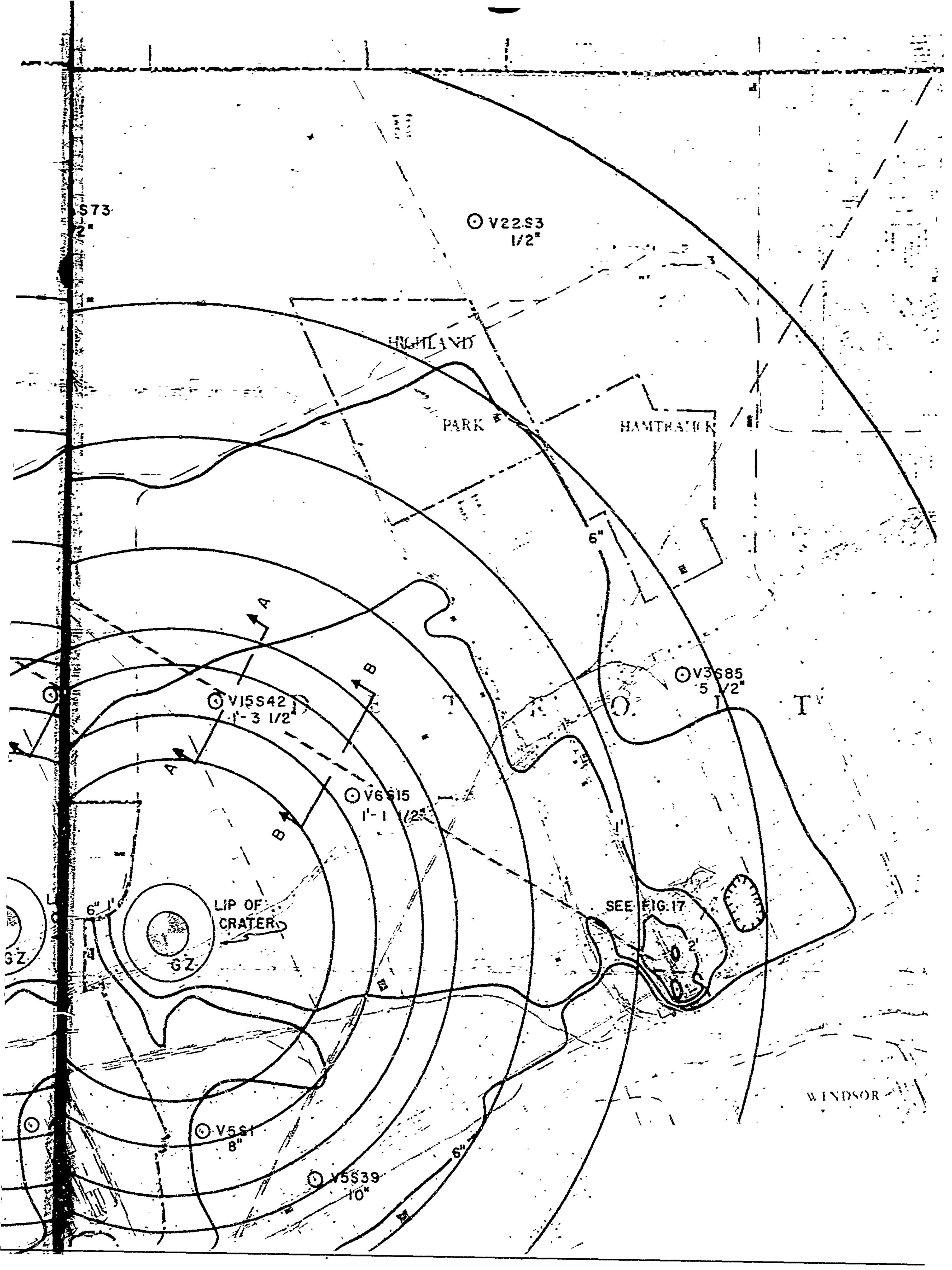
Name	Width FT.
MICHIGAN	100
WASHINGTON BLVD	80
LAFAYETTE	80
SHELBY	80
W. FORT	100
GRISWOLD	90
FEDERAL CT.	20

C

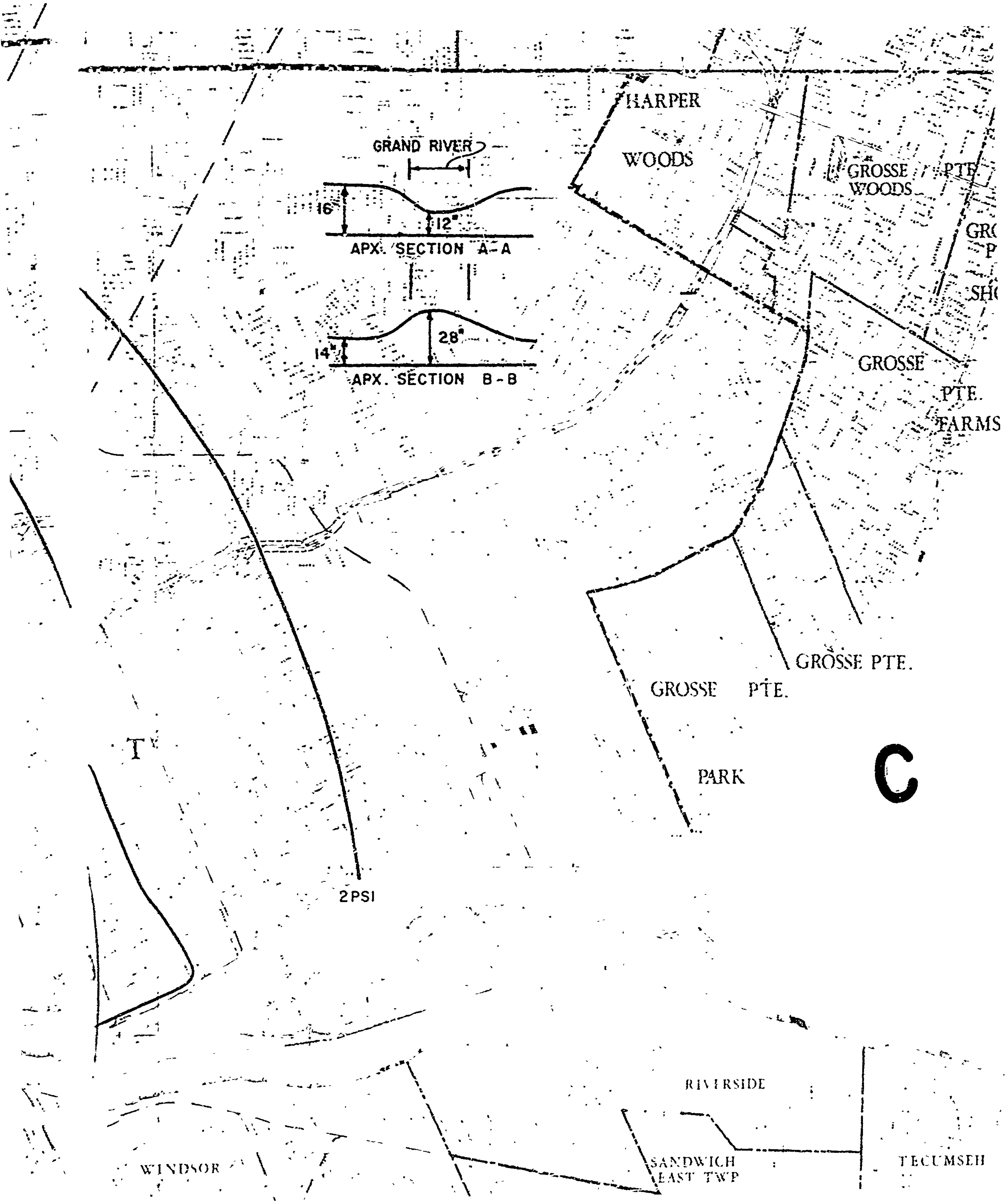
B-

Fig. B-1. Sample Data Sheet

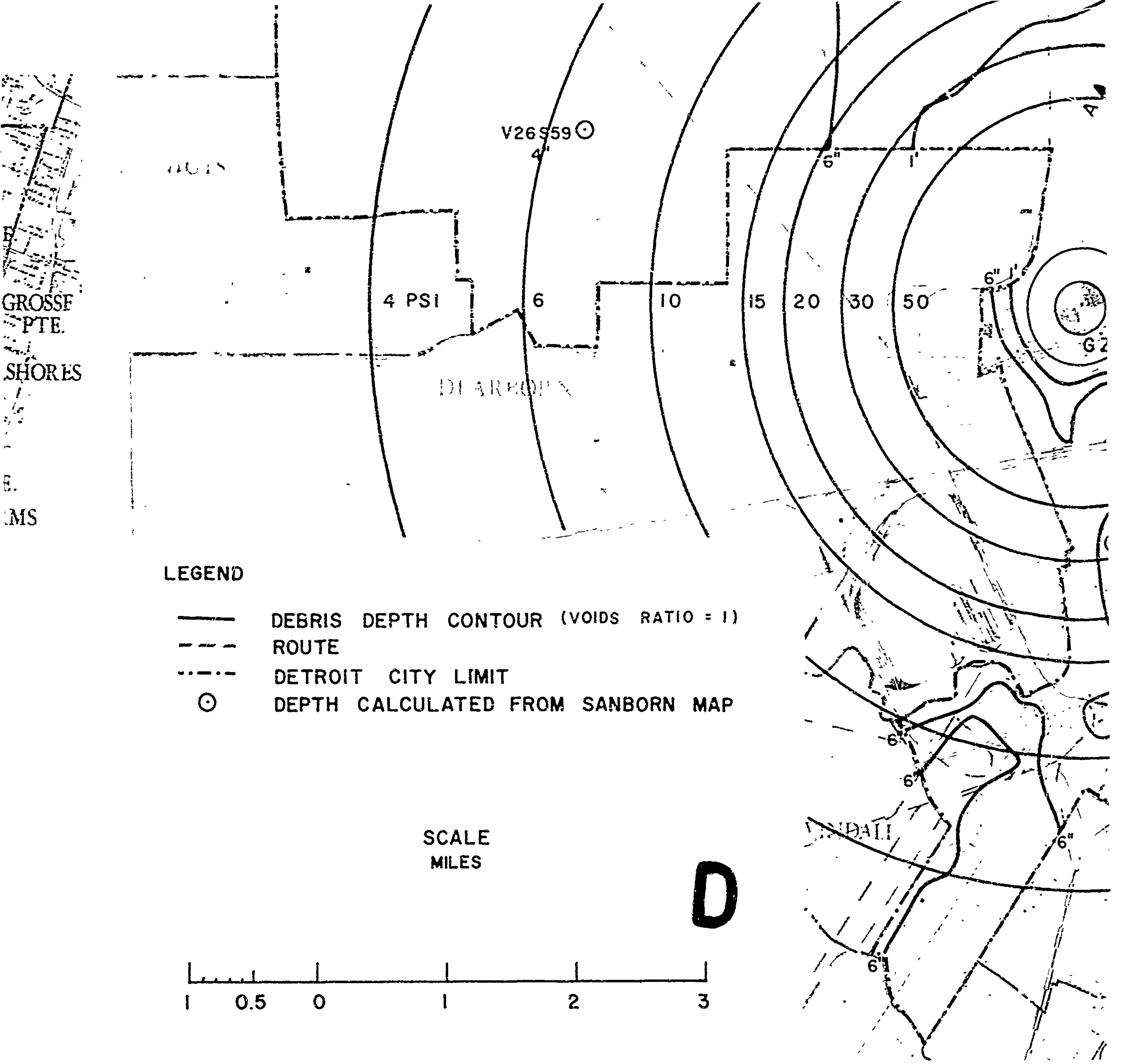

2 PSI
PARK
V17A S73
1 1/2"
V25 S50
2"
V25 S2
1 1/2"
TWP
V26 S59
4"
HGTS
6"
1'
4 PSI
6
10
15
20
30
50
6"
1'
GZ
DEARBORN
A
LEGEND
DEBRIS DEPTH CONTOUR (VOIDS RATIO = 1)
ROUTE
DETROIT CITY LIMIT

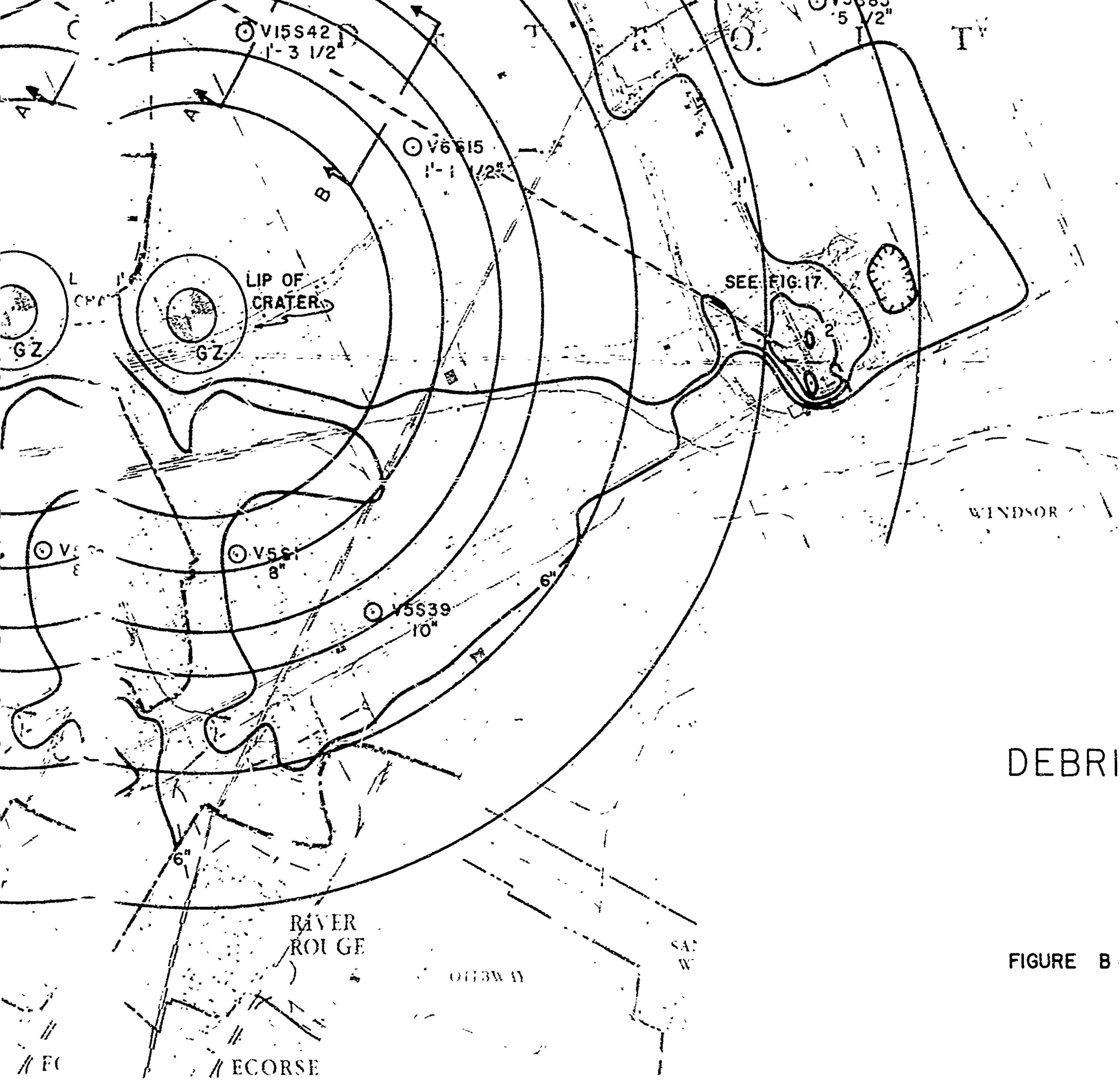


S73
2"
V22 S3
1/2"
HIGHLAND
PARK
HAMTRAMCK
6"
A
B
V3 S85
5 1/2"
V15 S42
1'-3 1/2"
V6 S15
1'-1 1/2"
1'
SEE FIG 17
2'
LIP OF
CRATER
GZ
6"
1'
V5 S1
8"
V5 S39
10"
WINDSOR



HARPER
WOODS
GROSSE
WOODS
PTE.
GRAND RIVER
16"
12"
APX. SECTION A-A
14"
28"
APX. SECTION B-B
GROSSE
PTE.
FARMS
GROSSE PTE.
GROSSE PTE.
PARK
C
2 PSI
RIVERSIDE
WINDSOR
SANDWICH
EAST TWP
TECUMSEH

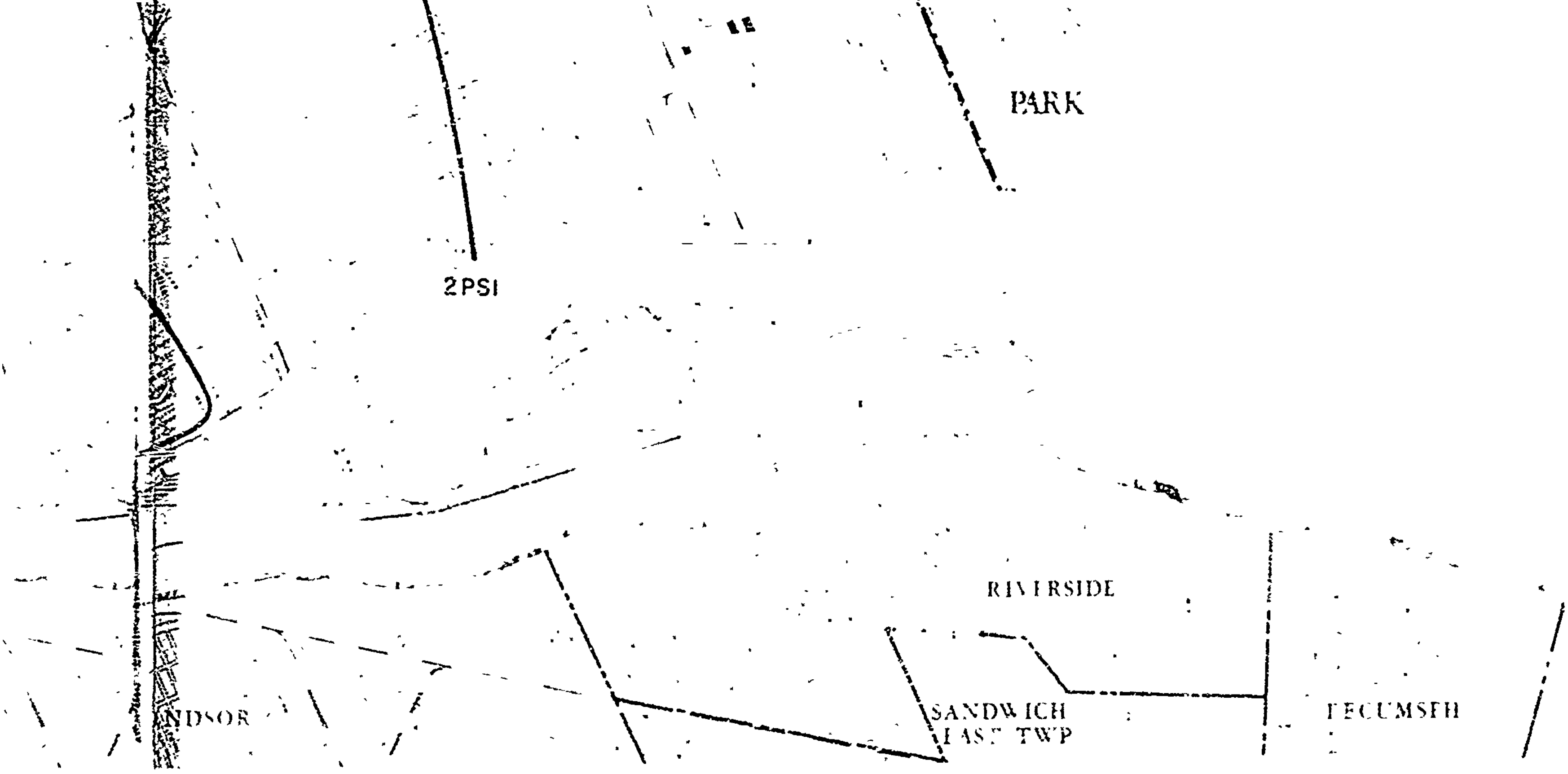

V26S59
4"
6"
1'
GROSSE
PTE.
SHORES
4 PSI
6
10
15
20
30
50
LEGEND
DEBRIS DEPTH CONTOUR (VOIDS RATIO = 1)
ROUTE
DETROIT CITY LIMIT
DEPTH CALCULATED FROM SANBORN MAP
SCALE
MILES
1 0.5 0 1 2 3
D



DEBRI

FIGURE B

E



RIS

DEBRIS DEPTH CONTOUR MAP

AIR BLAST ONLY

B - 3

FIGURE B - 3

URS 651-4

F

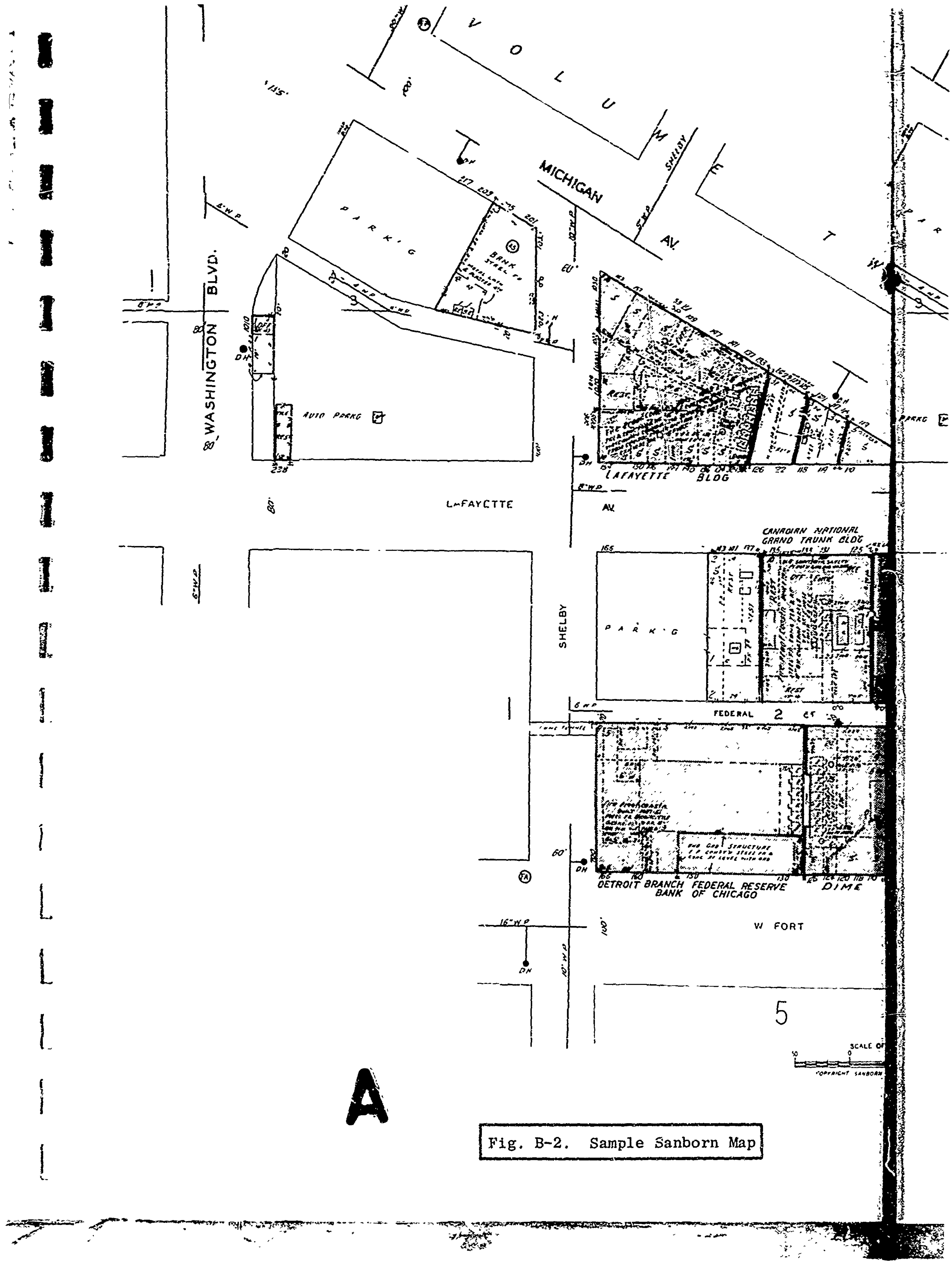


Fig. B-2. Sample Sanborn Map

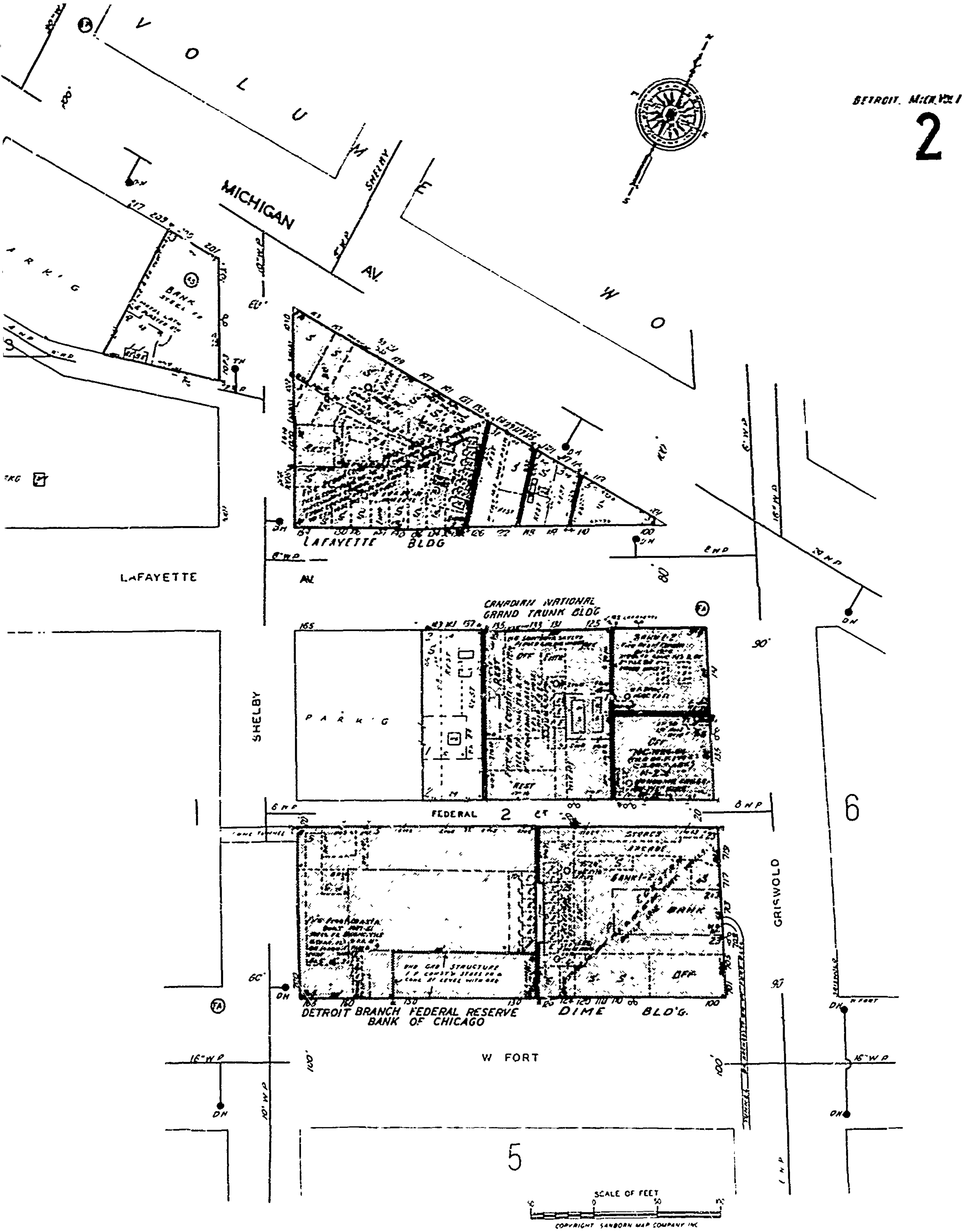
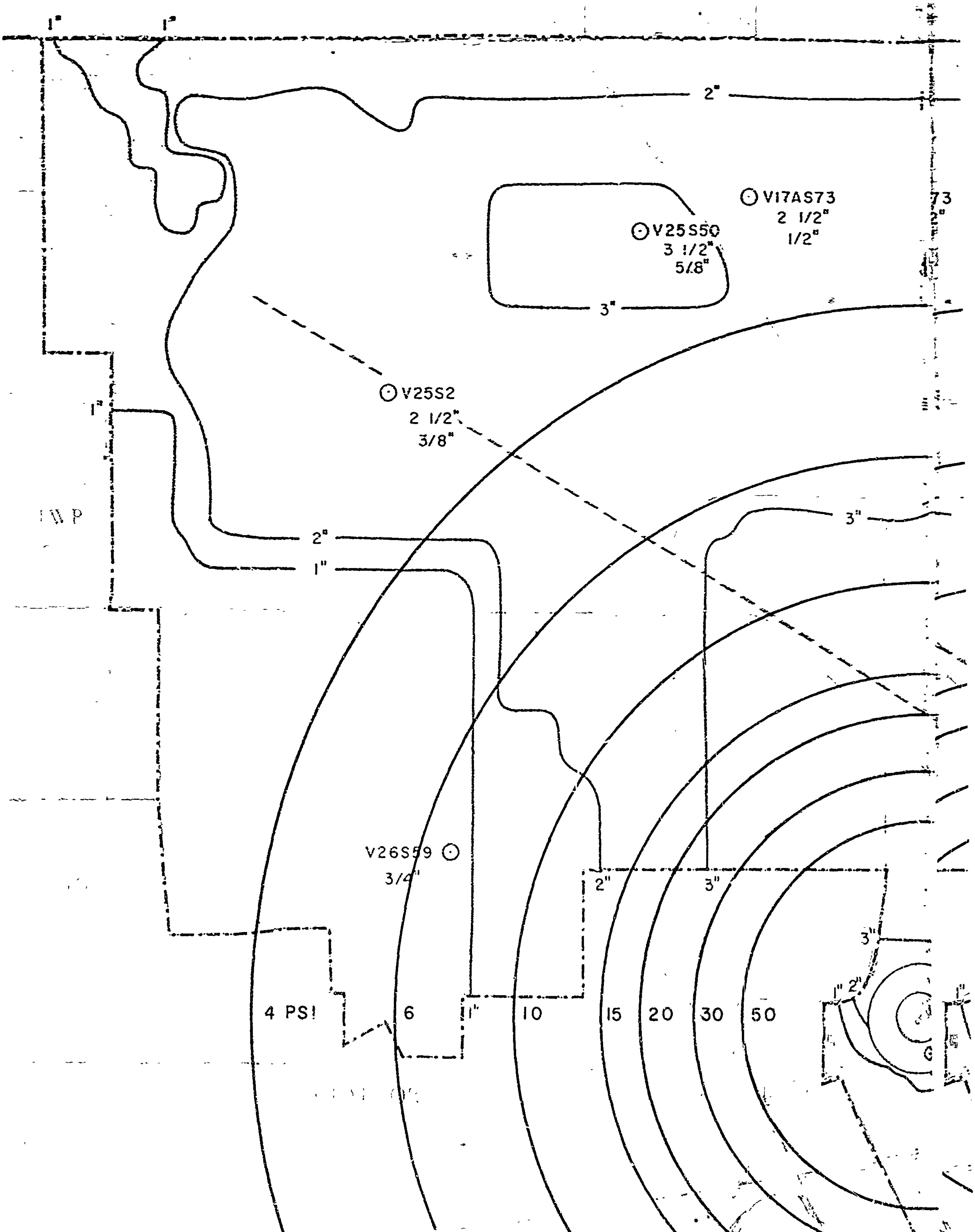


Fig. B-2. Sample Sanborn Map

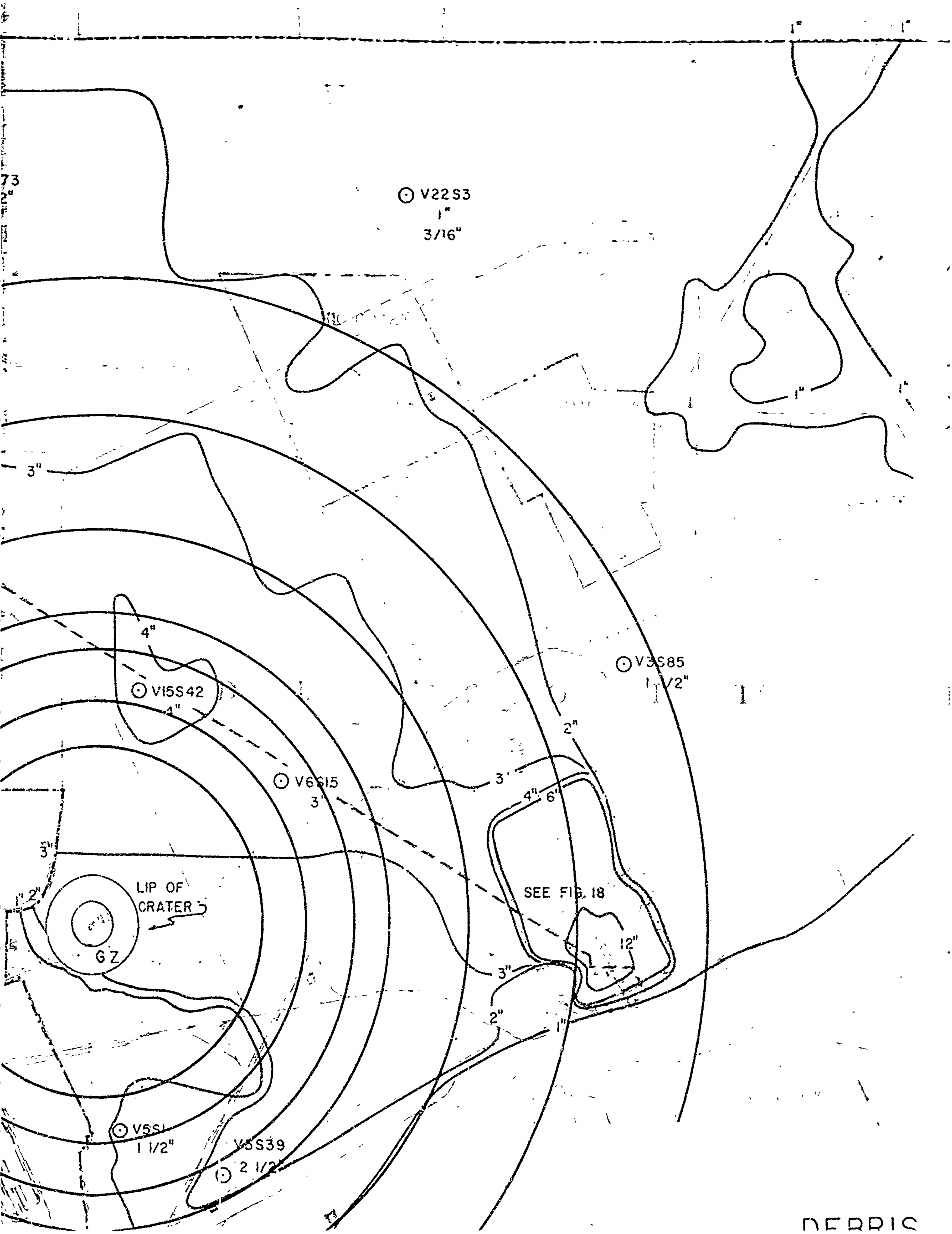
B



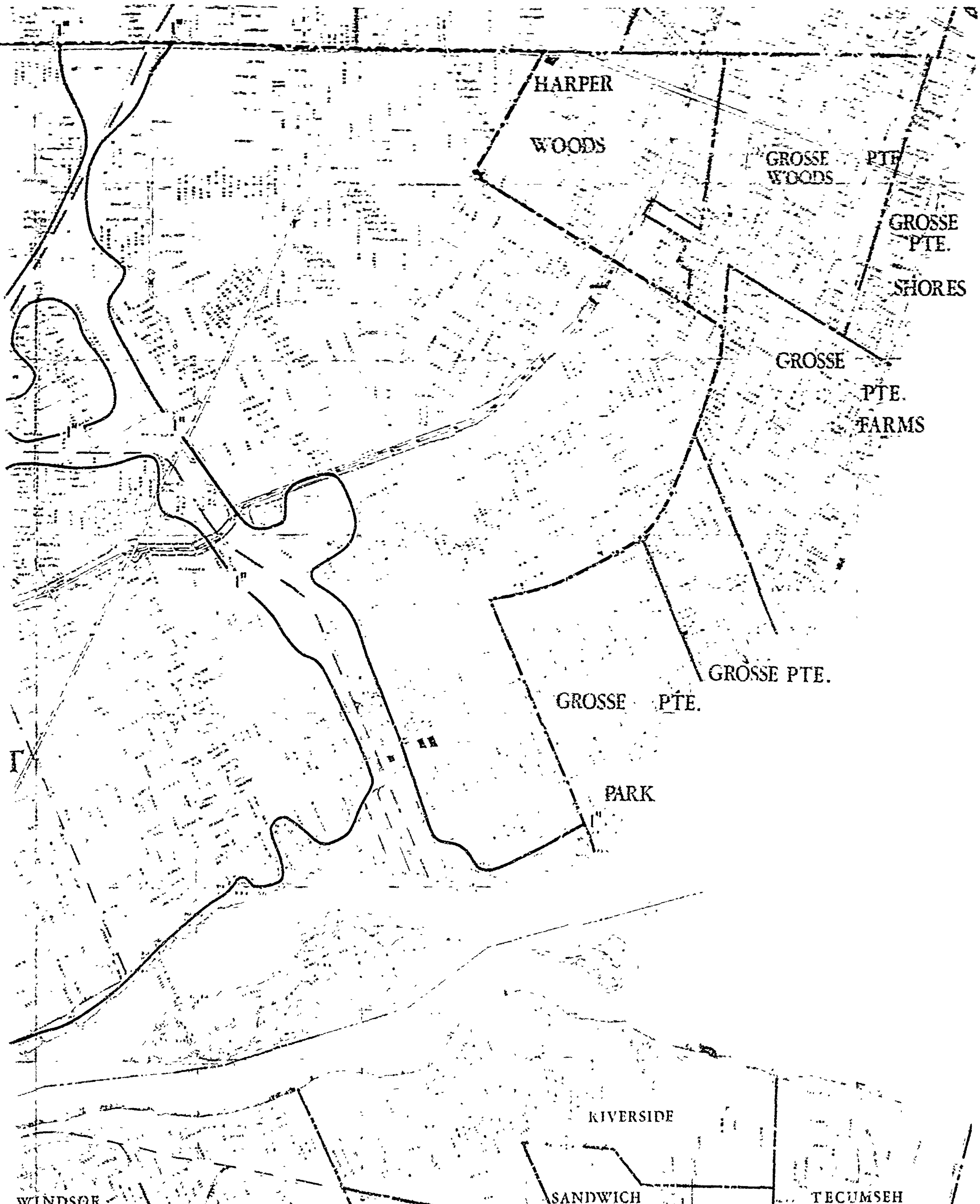
LEGEND

DEBRIS DEPTH CONTOUR (VOIDS RATIO = 1)

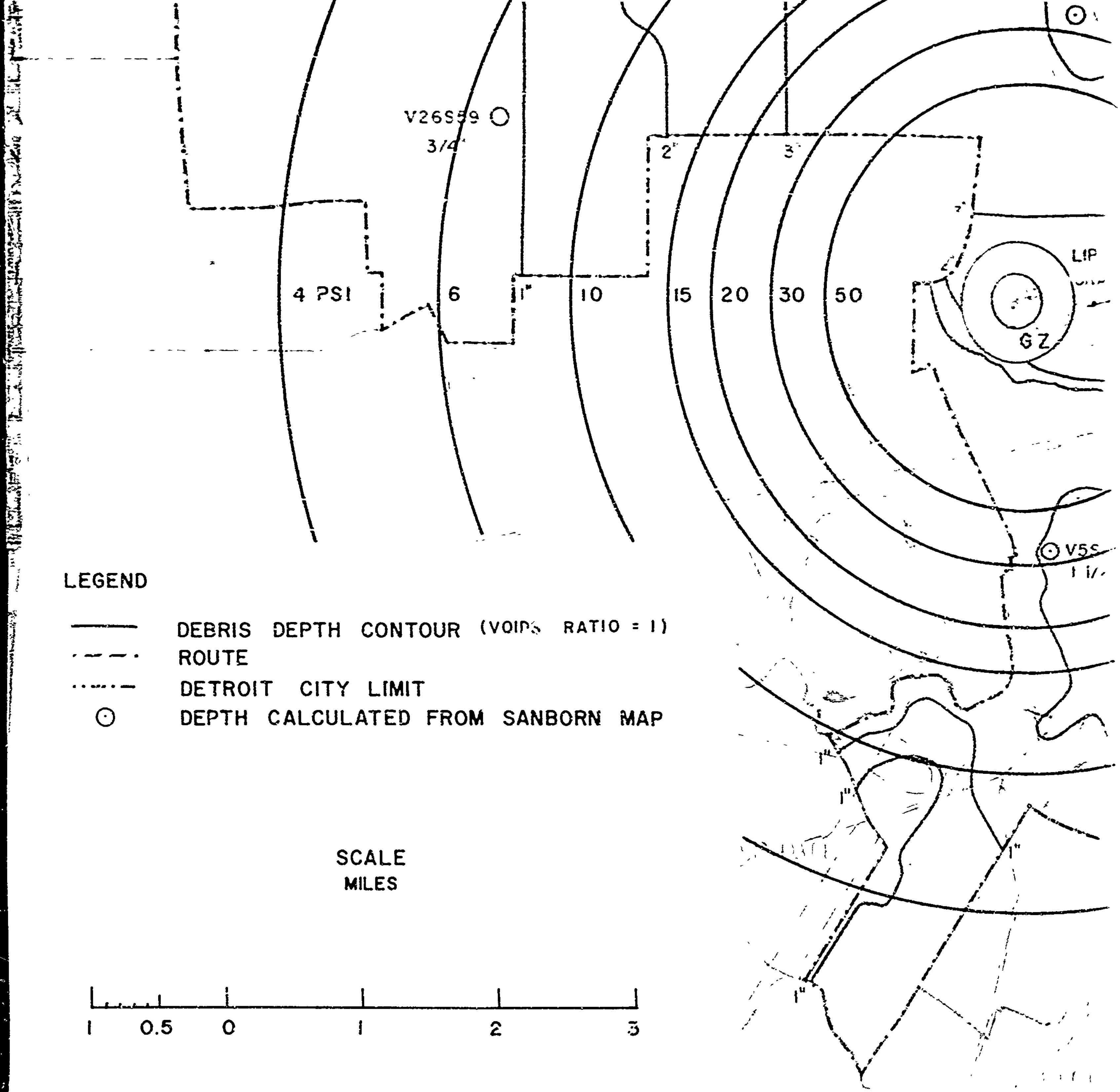
ROUTE



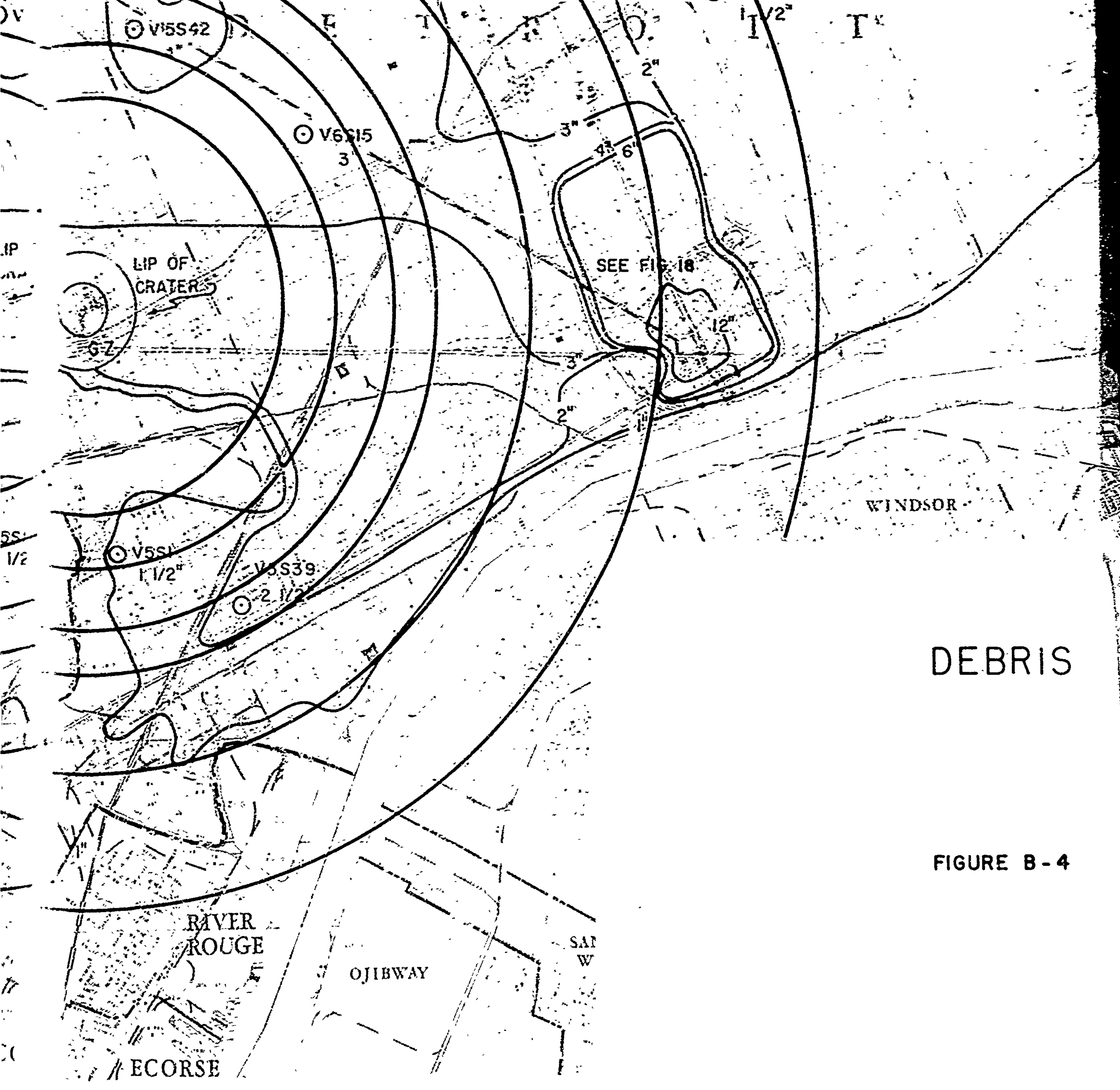
V22S3
1"
3/16"
3"
4"
V15S42
4"
V6S15
3"
V3S85
1 1/2"
2"
3"
4"
6"
SEE FIG. 18
12"
3"
2"
1"
LIP OF
CRATER
GZ
1" 2"
V5S1
1 1/2"
V5S39
2 1/2"
1"
1"
1"
DEBRIS



DEBRIS DEPTH CONTOUR MAP


V26S59
3/4"
2"
3"
4 PSI
6
1"
10
15
20
30
50
LIP
GZ
1"
1"
1"
1"
LEGEND
DEBRIS DEPTH CONTOUR (VOIDS RATIO = 1)
ROUTE
DETROIT CITY LIMIT
DEPTH CALCULATED FROM SANBORN MAP
SCALE
MILES
1 0.5 0 1 2 3

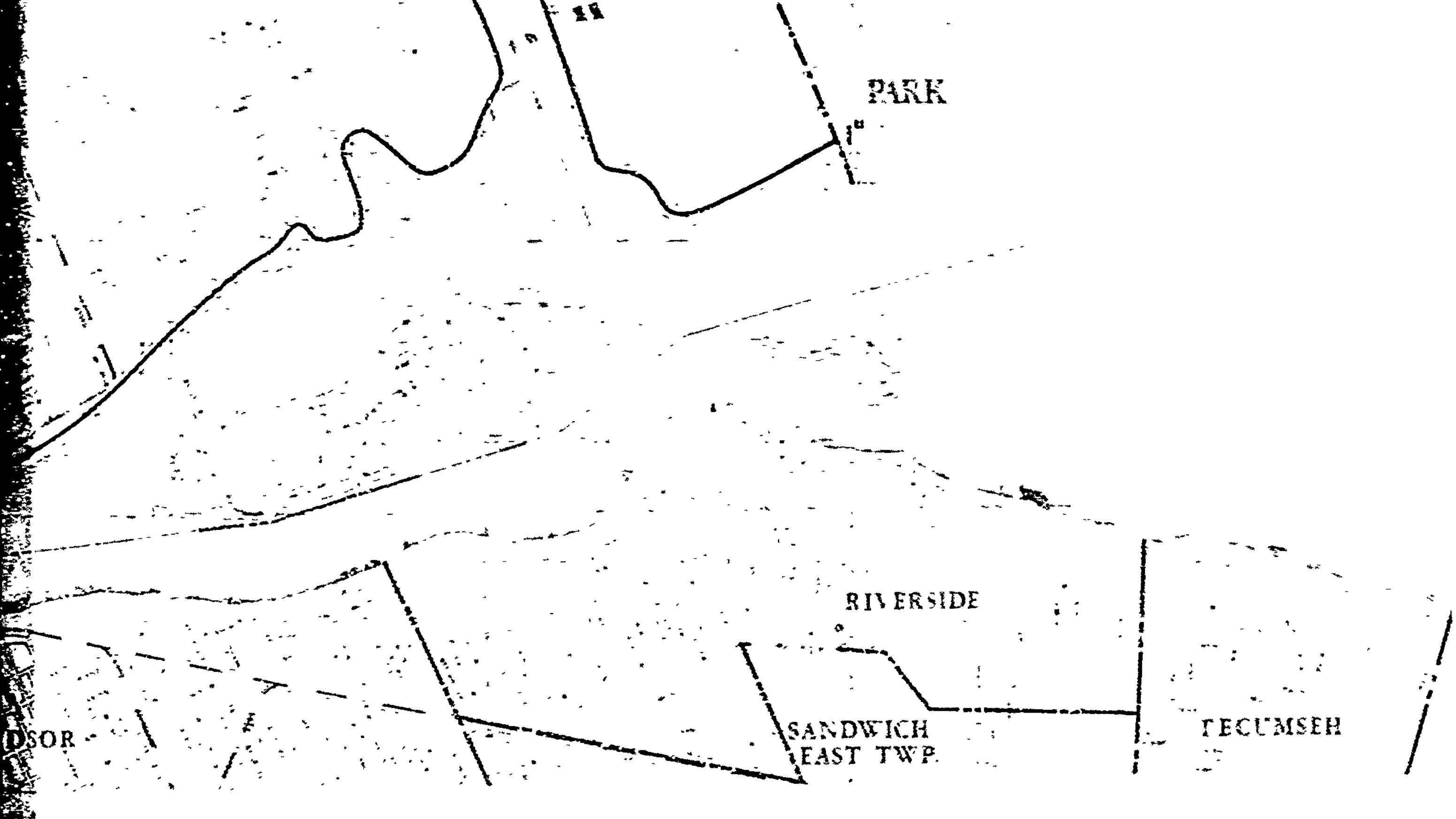
D



DEBRIS

FIGURE B-4

E



DEBRIS DEPTH CONTOUR MAP

FIRE AND AIR BLAST

FIGURE B-4

URS 651-4

F

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Formation of Debris From Buildings and Their Contents by Blast and Fire Effects of Nuclear Weapons

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report

5. AUTHOR(S) (Last name, first name, initial)

Rotz, J.; Edmunds, J.; Kaplan, K.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
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b. PROJECT NO. Work Unit No. 3312B	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	5D-11101-3312B-1

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13. ABSTRACT

The prime objective of this phase of work is to augment the debris prediction model with additional information (debris charts, failure overpressures, contents-debris criteria, estimating procedures and data, etc.) to facilitate its application and increase its range of applicability.

To this end, new debris charts are presented which cover a more complete and detailed range of building types, along with a tabulation of failure overpressures for miscellaneous small structures (towers, poles, stacks, etc.). Criteria are developed for determination of debris from the contents of buildings, and furnished with these (for ease of use) are data relating the amount of material contained in buildings to building occupancy.

A description of the debris prediction model and its operation and a detailed worked example are presented illustrating the use of the model to determine debris contours over an entire city (Detroit) and debris profiles along a route through the city. In this example, debris depths before and after fire and the percentage contribution by building contents and structural components in each case are given.

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Security Classification

14 KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Nuclear weapons, Air blast, Thermal effects, Structural debris, Damage vulnerability, Structural response, Buildings, Building contents, Postattack, Recovery, Reclamation						

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Summary Report

of

FORMATION OF DEBRIS FROM BUILDINGS AND THEIR CONTENTS BY BLAST AND FIRE EFFECTS OF NUCLEAR WEAPONS

April 1966

by

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URS CORPORATION
1811 Trousdale Drive
Burlingame, California

Prepared for

DEPARTMENT OF THE ARMY
Office of the Secretary of the Army
Office of Civil Defense
OCD-PS-64-201
Work Unit 3312B

FOREWORD

This report summarizes the information presented in URS 651-4, Formation of Debris From Buildings and Their Contents by Blast and Fire Effects of Nuclear Weapons, which is separately bound.

CONTENTS

Summary Report

of

FORMATION OF DEBRIS FROM BUILDINGS AND THEIR CONTENTS BY BLAST AND FIRE EFFECTS OF NUCLEAR WEAPONS

The objective of this phase of work was to construct additional debris charts (for 20-Mt and 20-kt yield weapons) for additional building types and more refined building type categories than those previously considered and to evaluate debris production from building contents. The debris charts and debris-from-contents data reflect both the presence and the absence of fire.

A worked example problem is also included to illustrate the application of the debris prediction model and the use of the newly developed charts and data. In this example, debris depth contours over an entire city (Detroit, Michigan) and debris depth profiles along a route through the city are presented.

STRUCTURAL DEBRIS CHARTS

The structure types common to urban complexes were categorized in accordance with their debris production and dynamic response characteristics. The type of materials used, the type of construction, and physical dimensions determine the amount of material in a particular building and, therefore, the amount of debris that would be produced by its destruction. The dynamic response characteristics of a building are determined primarily by its mass and the type of structural system. This, coupled with strength class of the building, determines the basic blast resistivity and, accordingly, the overpressures required to produce debris from failure of main structural components.

Classifying the buildings by type of components, type of structural system, and general strength class resulted in the following building types, for which new debris charts (Figs. 1 through 11) were constructed:

1. Heavy reinforced concrete multistory shear-wall buildings with light interior panels

2. Heavy reinforced concrete multistory shear-wall buildings with masonry interior panels

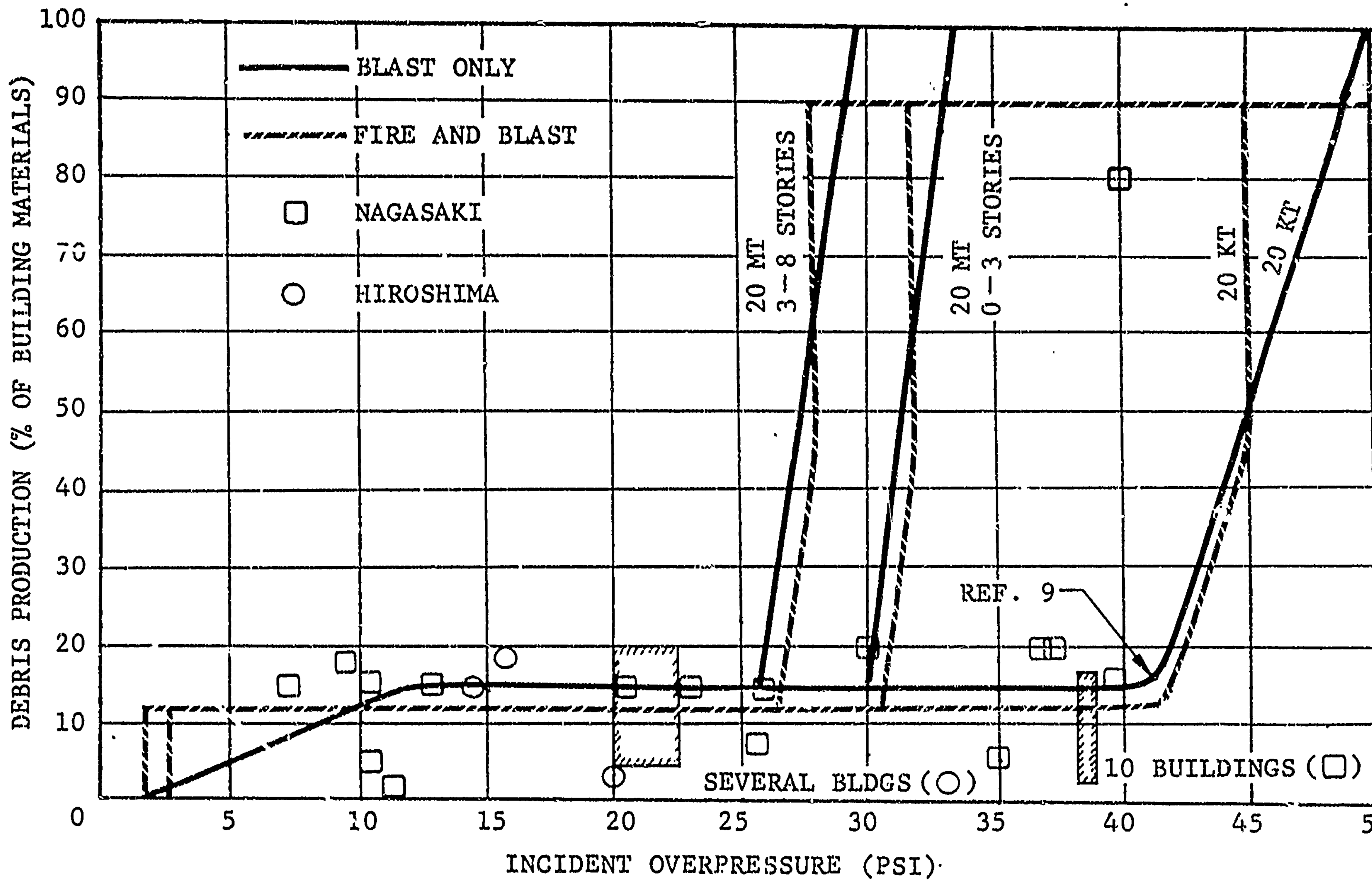

Fig. 1. Coupled Fire and Blast Percent Debris vs Overpressure — Heavy Reinforced Concrete Multistory Shear-Wall Buildings With Light Interior Panels

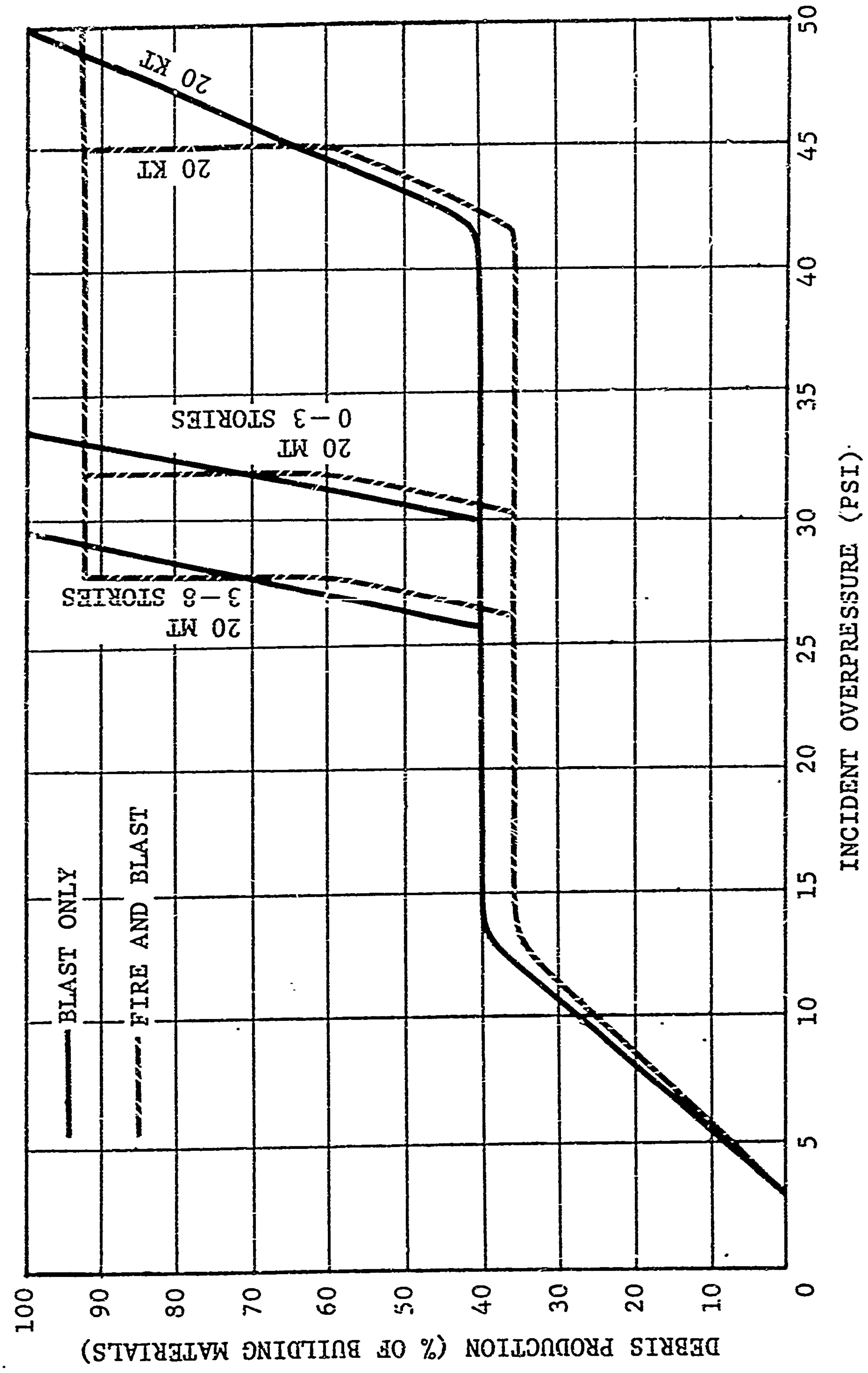

Fig. 2. Coupled Fire and Blast Percent Debris vs Overpressure — Heavy Reinforced Concrete Multistory Shear-Wall Buildings With Masonry Interior Panels

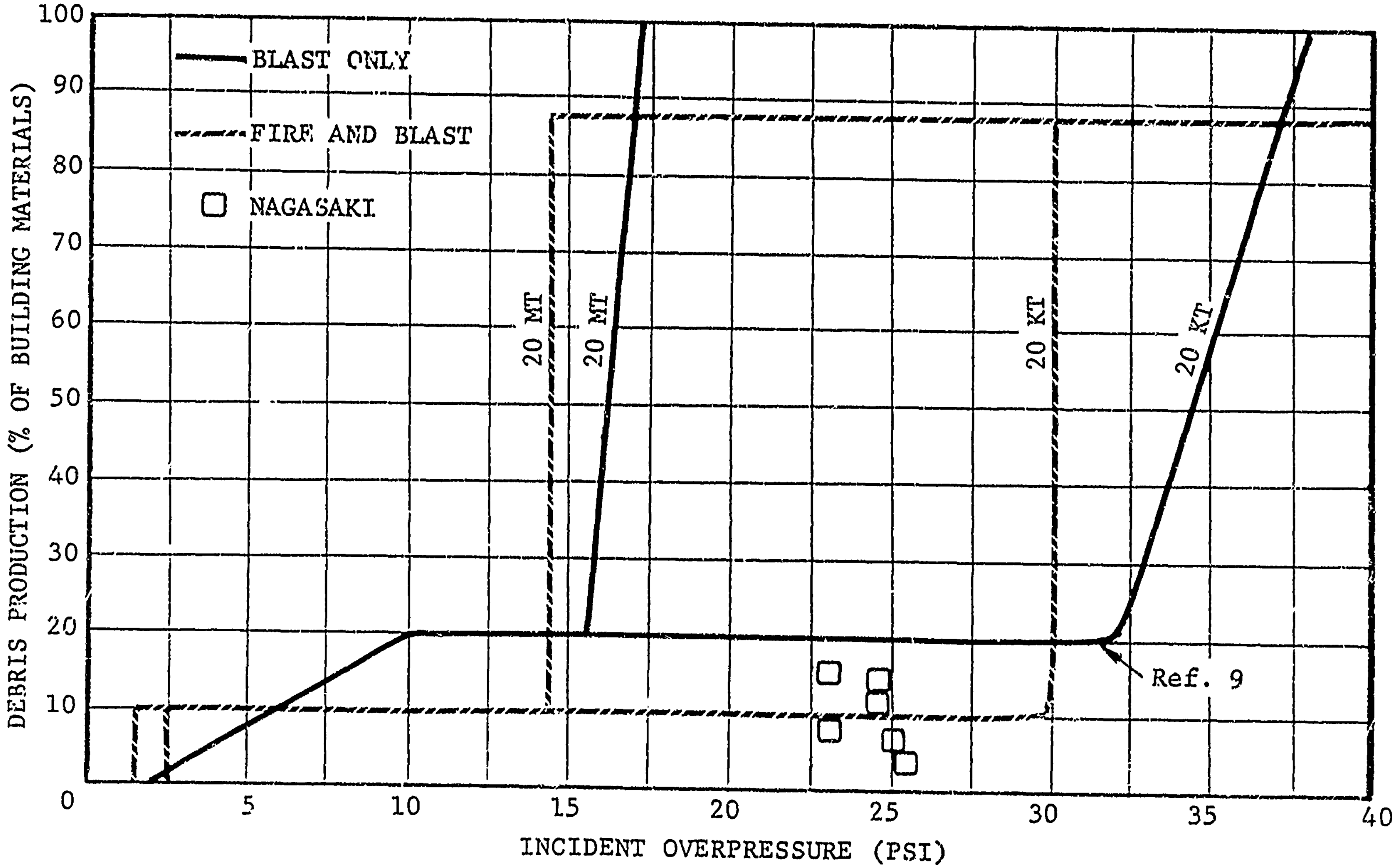

Fig. 3. Coupled Fire and Blast Percent Debris vs Overpressure – Multistory Steel and Reinforced Concrete Frame Buildings With Earthquake Design and Light Panels

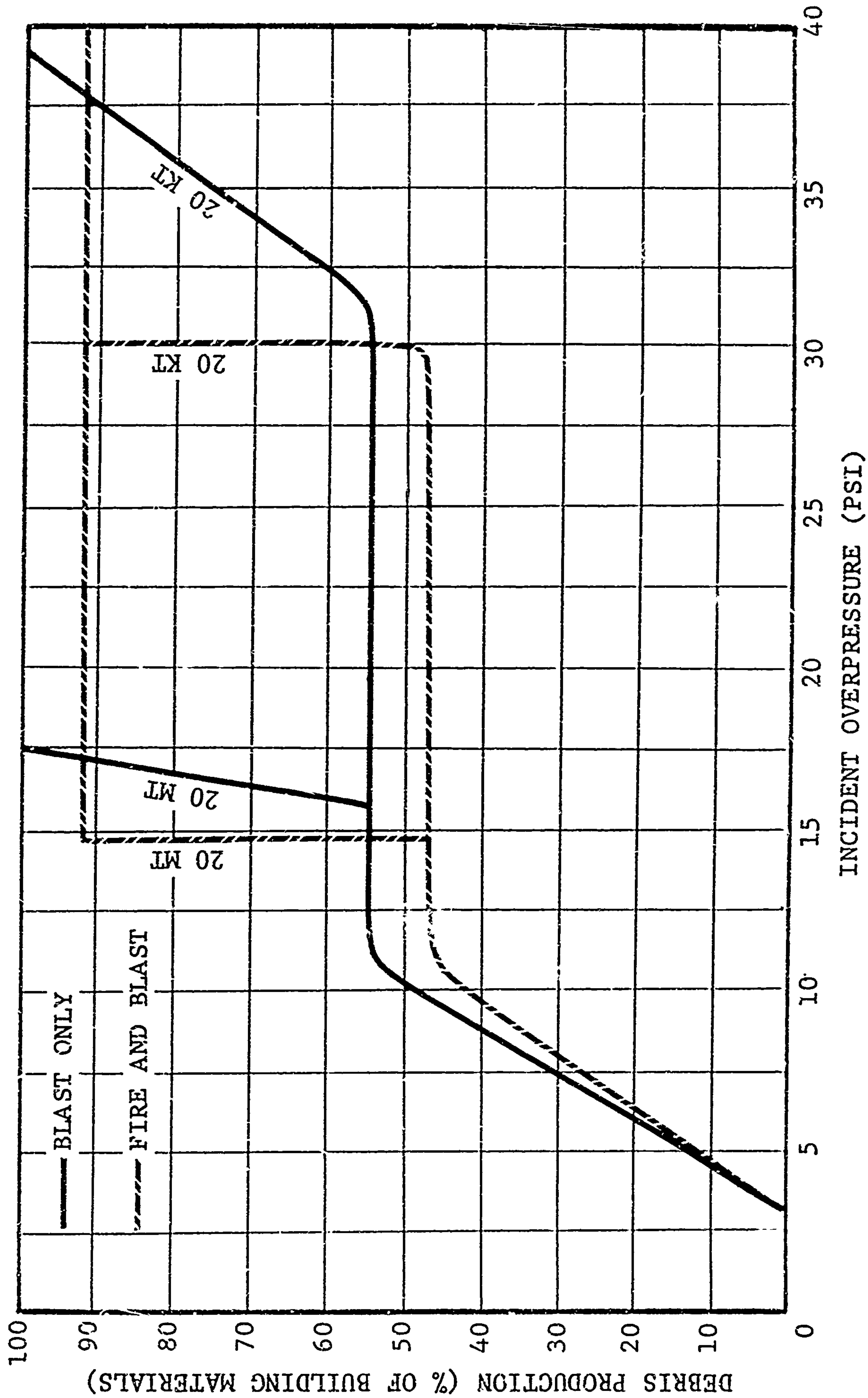

Fig. 4. Coupled Fire and Blast Percent Debris vs Overpressure – Multistory Steel and Reinforced Concrete Frame Buildings With Earthquake Design and Masonry Panels

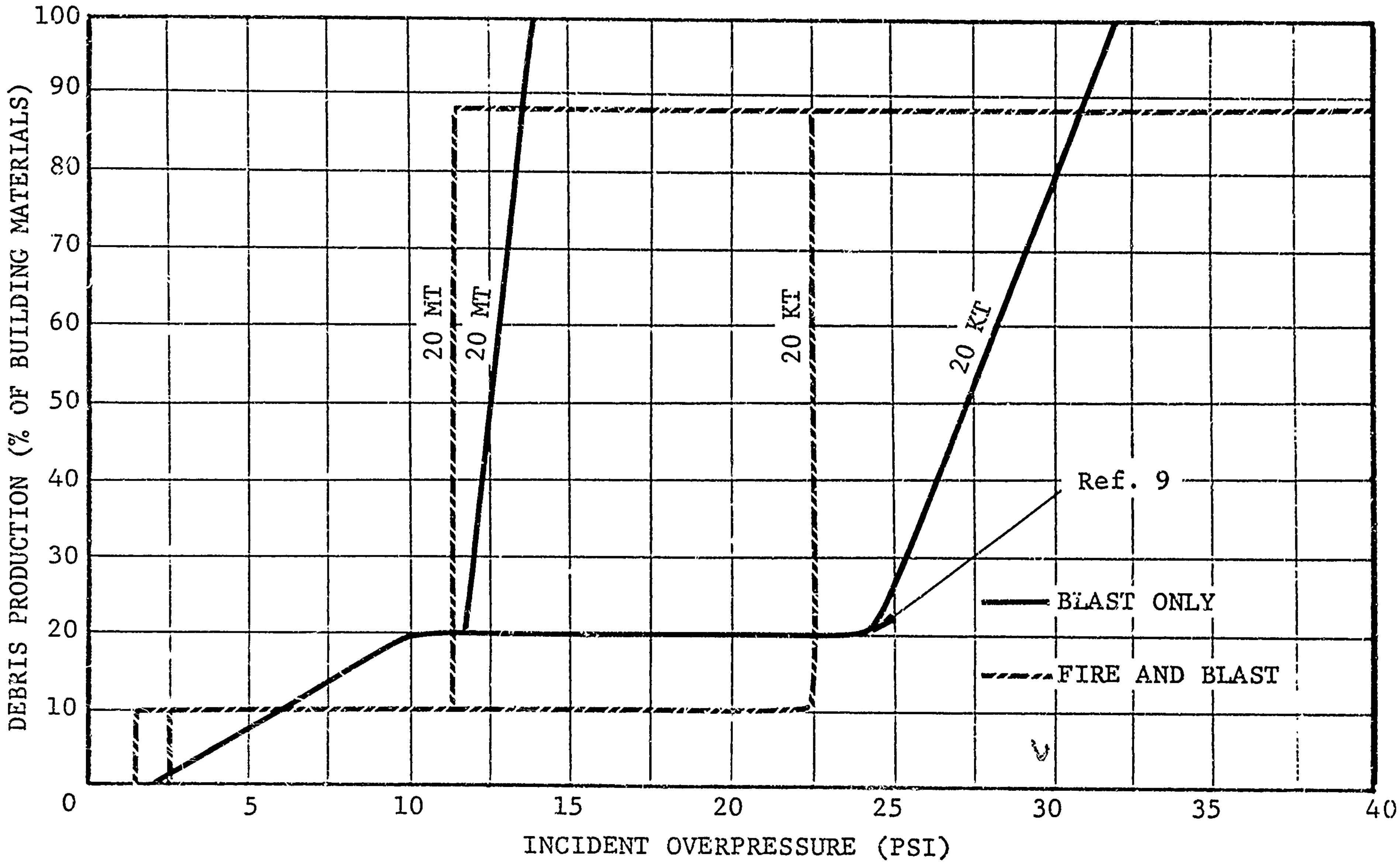

Fig. 5. Coupled Fire and Blast Percent Debris vs Overpressure — Multistory Steel and Reinforced Concrete Frame Buildings — Non-earthquake Design With Light Panels

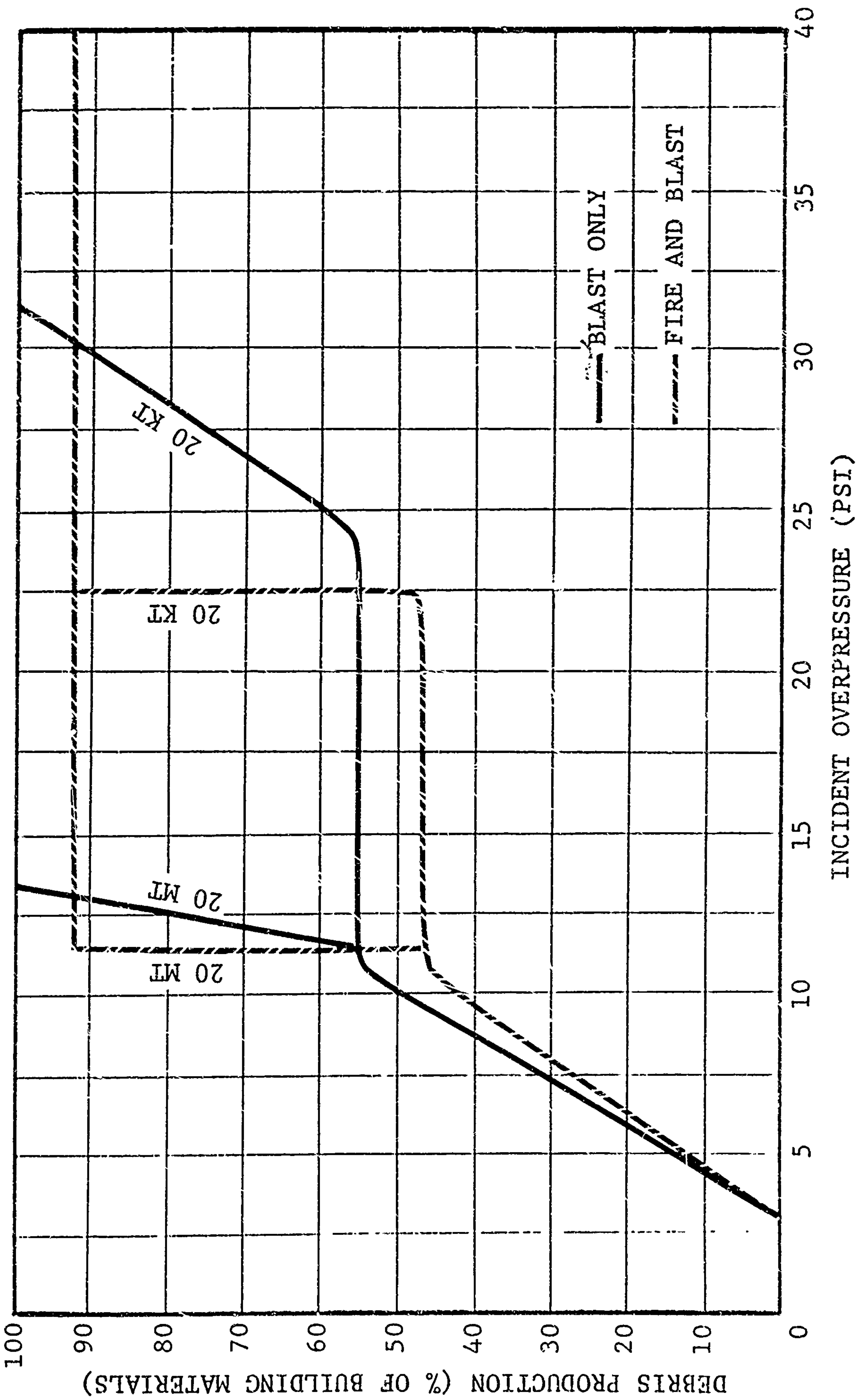

Fig. 6. Coupled Fire and Blast Percent Debris vs Overpressure — Multistory Steel and Reinforced Concrete Frame Buildings — Non-earthquake Design With Masonry Panels

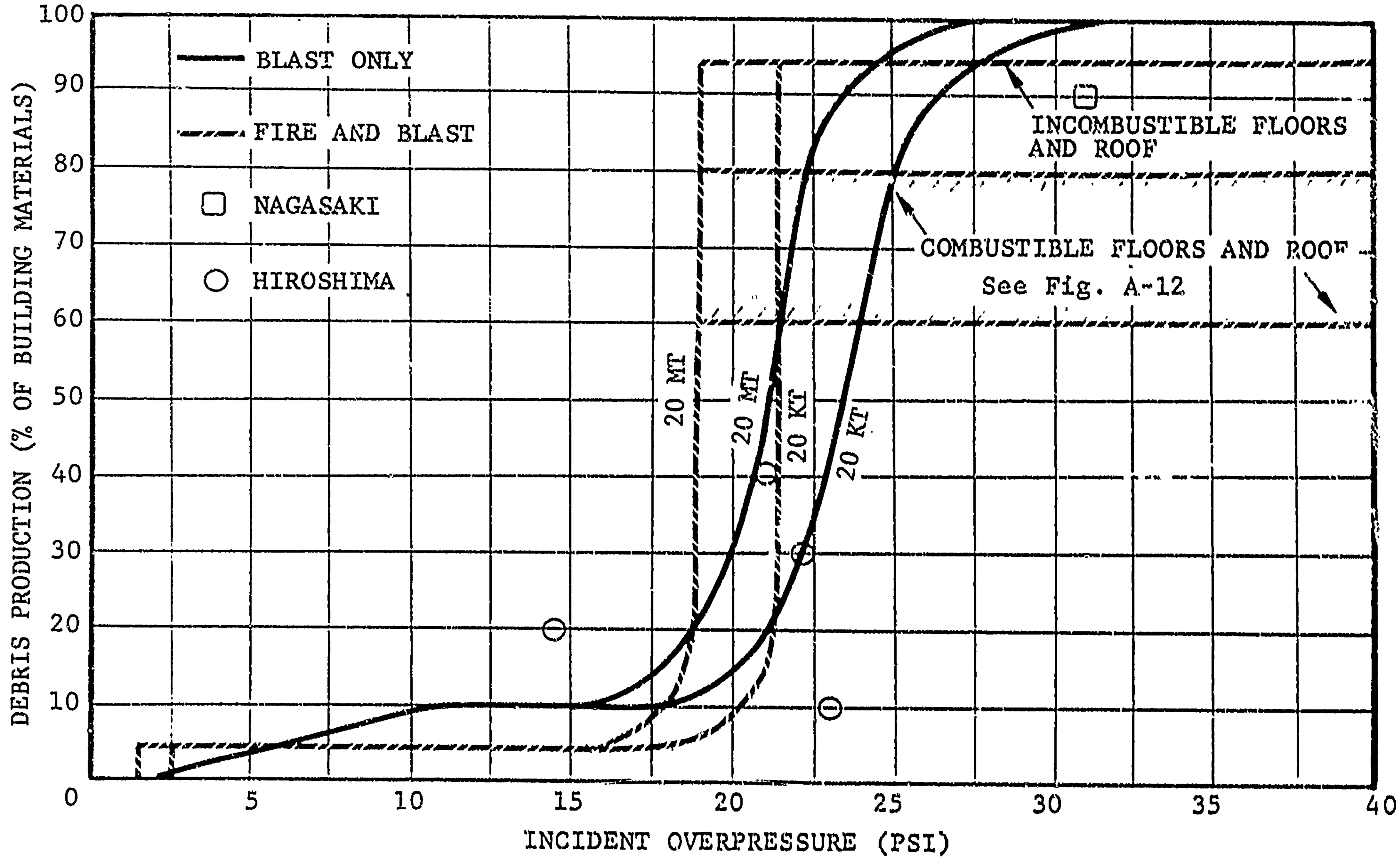

Fig. 7. Coupled Fire and Blast Percent Debris vs Overpressure — Load-Bearing Masonry Building With Reinforcing or Reinforced Concrete Spandrels

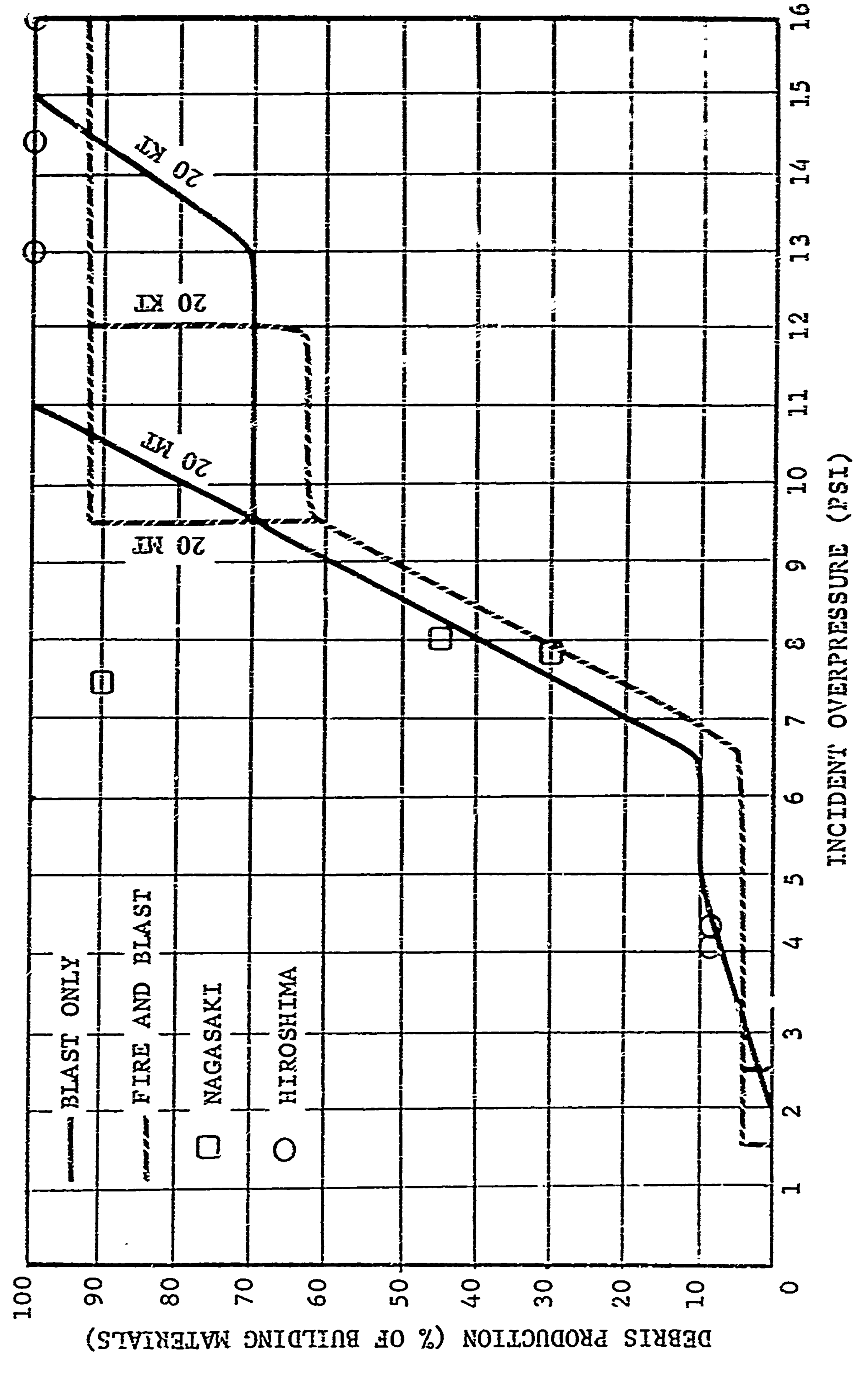

Fig. 8. Coupled Fire and Blast Percent Debris vs Overpressure — Light Reinforced Concrete Shear-Wall Buildings With Concrete Roof and Light Interior Panels

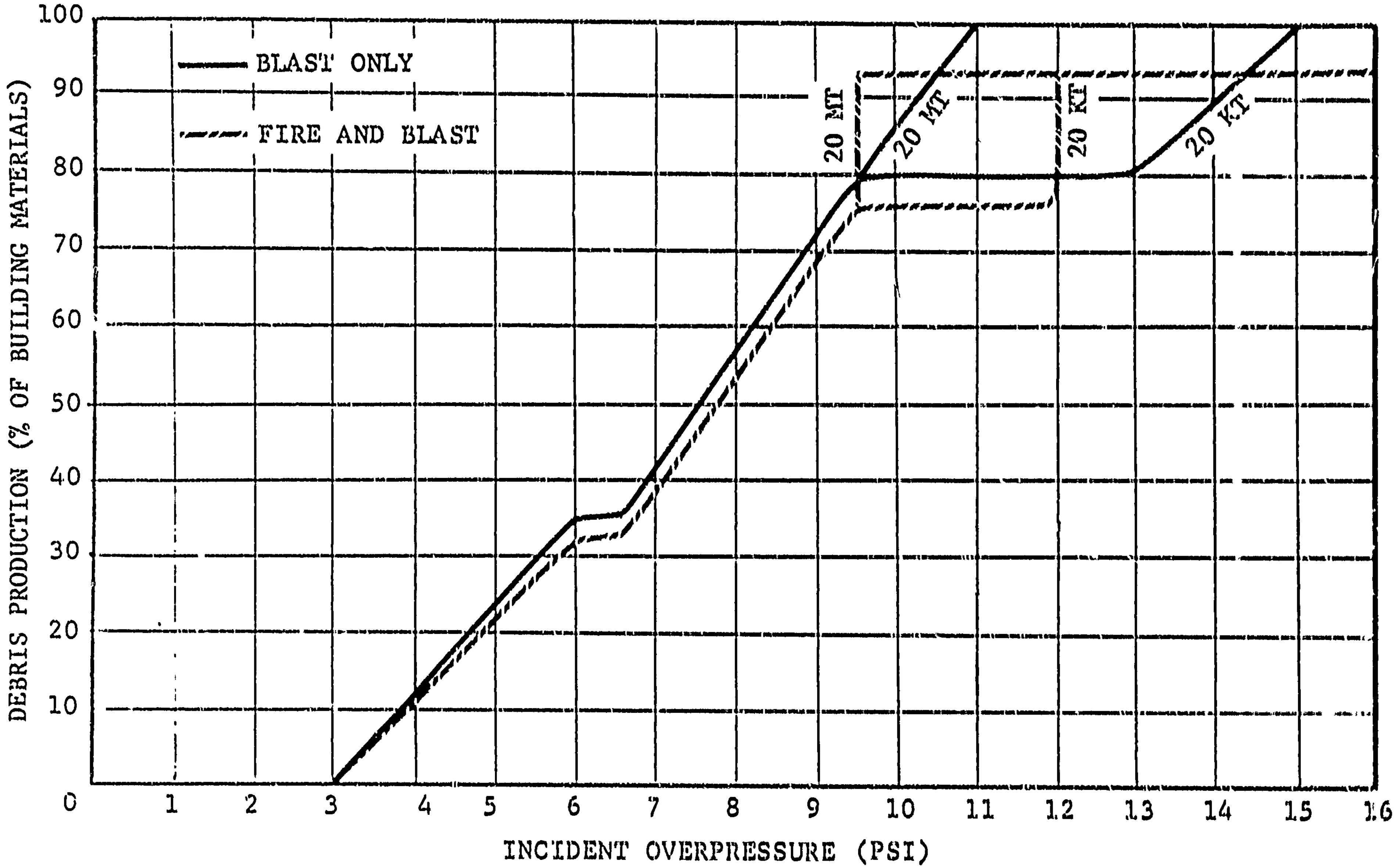

Fig. 9. Coupled Fire and Blast Percent Debris vs Overpressure — Light Reinforced Concrete Shear-Wall Buildings With Concrete Roof and Masonry Interior Panels

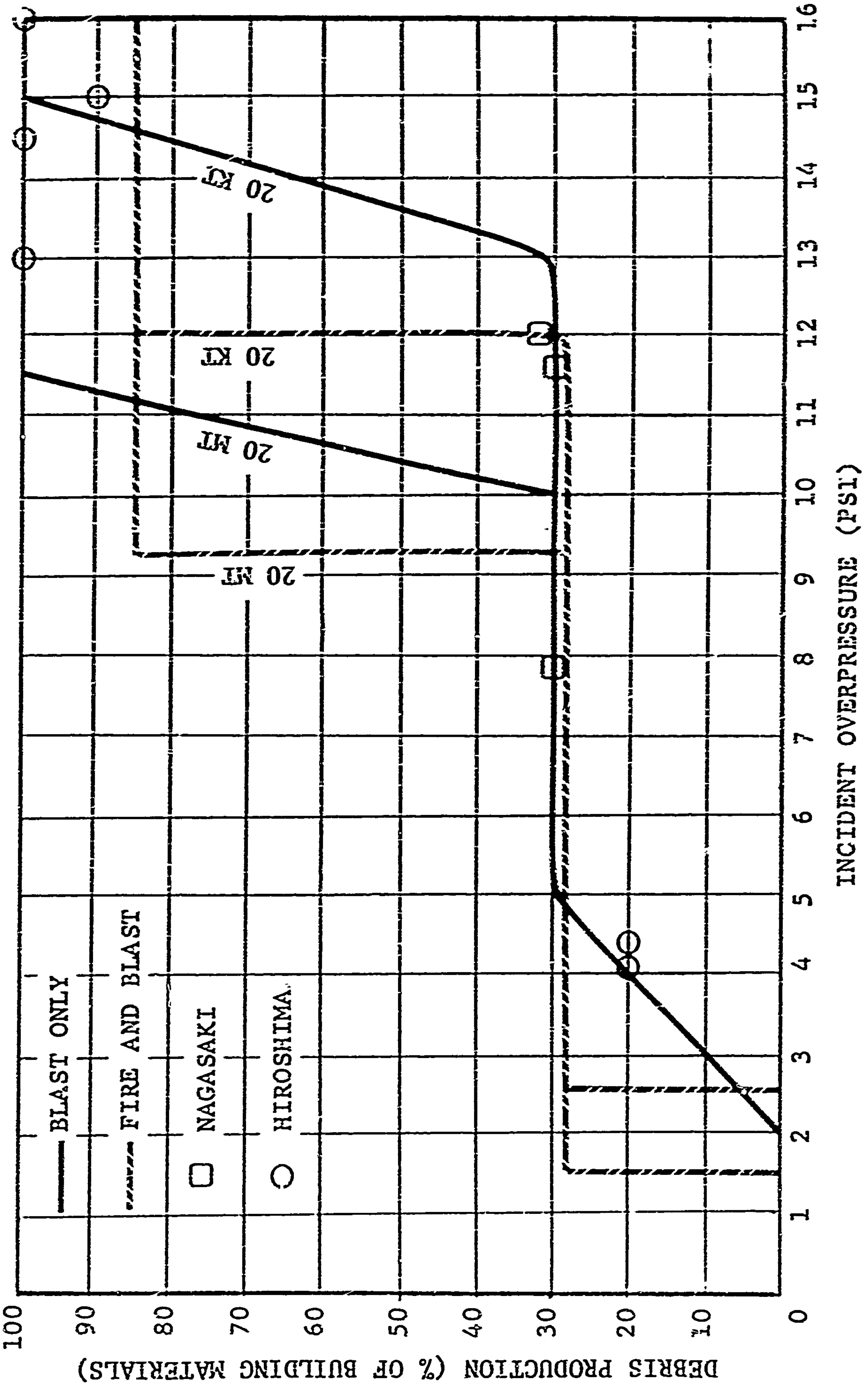

Fig. 10. Coupled Fire and Blast Percent Debris vs Overpressure — Light Reinforced Concrete Shear-Wall Buildings With Mill-Type Roof and Light Interior Panels

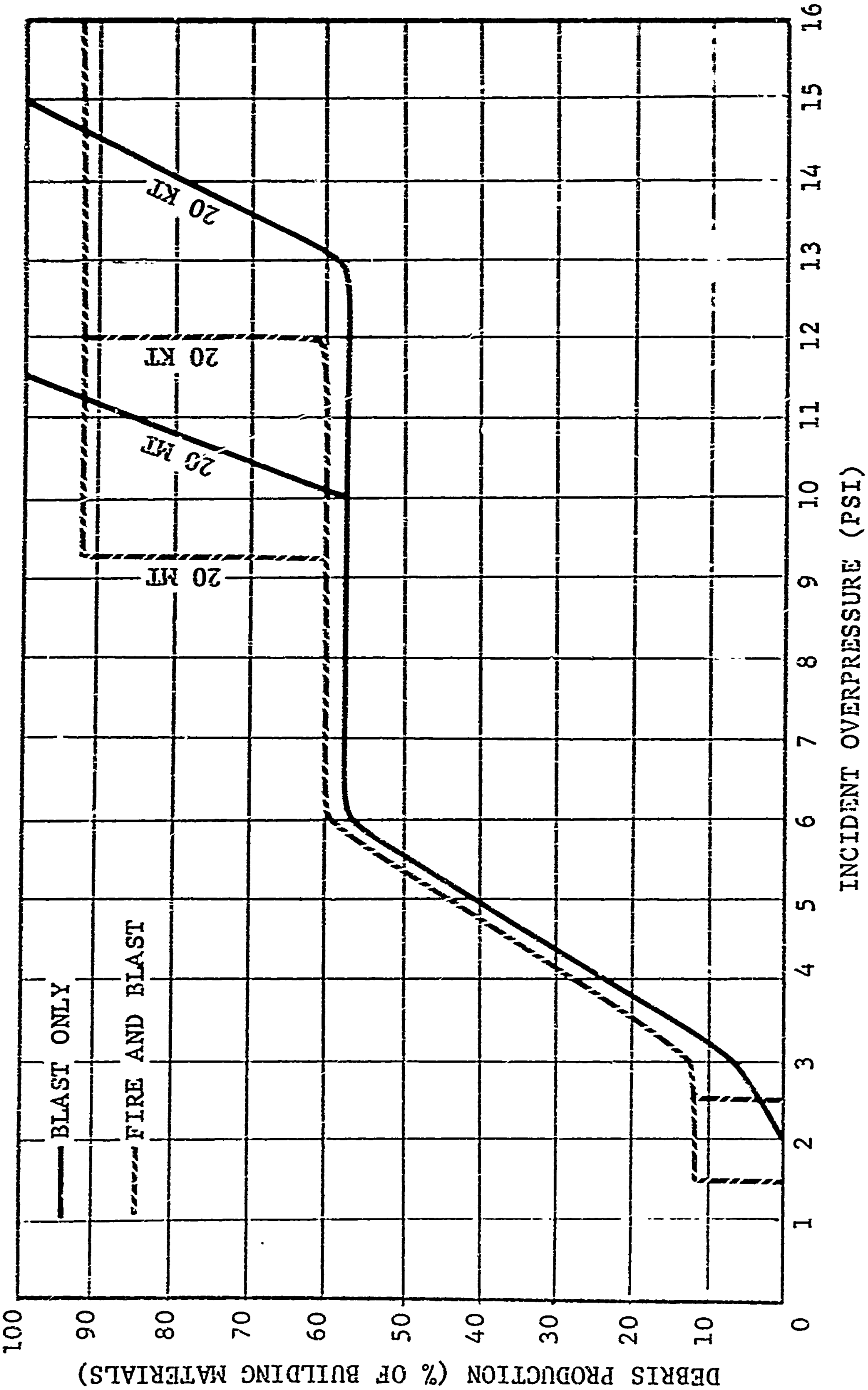

Fig. 11. Coupled Fire and Blast Percent Debris vs Overpressure — Light Reinforced Concrete Shear-Wall Buildings With Mill-Type Roof and Masonry Interior Panels

3. Steel and reinforced concrete multistory frame buildings with earthquake design and light panels

4. Steel and reinforced concrete multistory frame buildings with earthquake design and masonry panels

5. Steel and reinforced concrete multistory frame buildings — nonearthquake design with light panels

6. Steel and reinforced concrete multistory frame buildings — nonearthquake design with masonry panels

7. Load-bearing masonry buildings with reinforcing or reinforced concrete spandrels

8. Light reinforced concrete shear-wall buildings with concrete roof and light interior panels

9. Light reinforced concrete shear-wall buildings with concrete roof and masonry interior panels

10. Light reinforced concrete shear-wall buildings with mill-type roof and light interior panels

11. Light reinforced concrete shear-wall buildings with mill-type roof and masonry interior panels

All these buildings vary considerably with respect to debris production when acted upon by blast and fire. Portions of the charts reflecting the effects of fire on debris production were constructed in accordance with information presented in URS Report 639-9.

SMALL-STRUCTURE FAILURE OVERPRESSURE

In reviewing the damage information for construction of the new debris charts, note was also made of overpressures at which miscellaneous, small, primarily drag-sensitive structures failed. These structures, although generally insignificant, may figure prominently in some specific analyses. Consequently, failure overpressures for these structures were assembled and tabulated for the 20-kt and 20-Mt weapons and are presented in Table 1.

Table 1

FAILURE OVERPRESSURES FOR SMALL DRAG-SENSITIVE
STRUCTURES AND ELEMENTS
(20-kt and 20-Mt weapons)

Description	Overpressure at Failure (psi) 20 kt	20 Mt
Transmission Poles:		
Radial Lines	8	3.8
Transverse Lines	9	4.5
Transmission Towers	10	5
Average Forest	8	3.8
Stacks		
Reinforced Concrete:		
Over 4 ft diameter	25	11
4 ft and smaller diameter	15	7
Steel	5.5	2.6
Brick	5	4.5 (estimated)

DEBRIS FROM CONTENTS OF BUILDINGS

Building contents were found to make an appreciable contribution to debris production, the amount being determined by the use or occupancy and the floor area of the building.

Information collected for determination of design criteria for buildings of various occupancy was utilized to develop the data presented in Table 2, from which the volume of contents can be calculated. The average total floor load (in pounds per square foot) and the combustible contribution are given in addition to the volume factor (K) to provide the capability of finding the total weight of the contents as well as the total volume. To find the volume of contents of a particular building, its use or occupancy is determined; the number of stories (N) and its plan area are found; the K factor (with or without fire) is determined from Table 2; and the following simple formula applied:

$$V = KA_pN$$

where:

V = Volume (packed) in cubic feet (voids ratio = 0)

A_p = Plan area of building in square feet

N = Number of stories

The weight of contents can be found by similar calculations, using the average floor loads given.

The following criteria were adopted for determination of when building contents become debris:

Action	Contents Considered as Debris
Contents ejected by blast	yes
Contents destroyed by fire	yes
Contents destroyed by blast	yes
Building destroyed by blast or fire	yes
Contents displaced by blast but not destroyed or ejected	no

Table 2

BUILDING CONTENTS LOADS AND VOLUME FACTORS

Occupancy	PSF Combustible	PSF Total	Volume Factor K ($V = KA_pN$)* Total	After Fire
Apts. and Residential	3.5	5	0.625	0.02
Auditoriums and Churches	1	1.5	0.25	0.007
Garage				
Storage	1	15	0.75	0.30
Repair	1	11	0.55	0.20
Gymnasium	0.3	0.5	0.09	0.003
Hospitals	1.2	3	0.375	0.03
Hotels	4	5	0.625	0.013
Libraries	24	26	0.75	0.027
Manufacturing				
Comb. Mdse. fabrics, furniture	13.5	18	1.8	0.07
Incombustible	1	11	0.55	0.20
Offices	7	12	1.2	0.10
Printing Plant				
Newspaper	10	23	0.9	0.20
Books	50	60	1.7	0.13
Schools	9.5	11	1.6	0.02
Storage				
Gen. Mdse.	14	25	6	0.3
Special		**		
Stores				
Retail Dept.	7.5	12	2	0.10
Wholesale	10	16	2.7	0.12
Restaurant	2	3.5	0.6	0.02

* V = Volume in cubic feet
A_p = Plan area in square feet
N = Number of stories

** 25 percent of design load.

In applying the destruction and ejection criteria, the fate of the building contents is assumed to parallel that of the interior building panels. For most situations this assumption will be realistic. Obvious cases where this rule would be inapplicable (such as permanently installed industrial machinery) should, of course, be treated separately.

EXAMPLE

The example problem utilizes the Five-City Study attack on Detroit, Michigan. In this example the debris prediction model was used to calculate debris depth for construction of debris contours (with and without fire) covering the entire city, for construction of debris profiles along a route through the city, and for investigation of detours and rerouted sections. Figures 12 and 13 are scaled-down versions of the debris contours. Figure 14 shows overpressure isobars and the route through the city, for which the composite debris profiles shown in Fig. 15 were constructed. Detouring localized areas of greater debris depth and selecting an alternate route through the central commercial section of the city resulted in reducing the amount of debris that would be encountered by nearly a factor of three. For details, see larger scale figures, photographs, and descriptions contained in the body of the main report.

Also included in the report is a detailed description of the debris prediction model and an appendix containing all pertinent information developed to date (debris charts, small-structure failure overpressures, building contents data, formulae for estimating structural volumes, etc.).

CONCLUSIONS

The additional curves, building contents criteria, assembled data, empirical formula, and other improvements provided during this phase have refined and added to the versatility of the debris prediction model.

The example problem presented in this report illustrates the potential of this model for general debris investigations (debris contours) as well as specific detailed investigations (debris depths along a route).

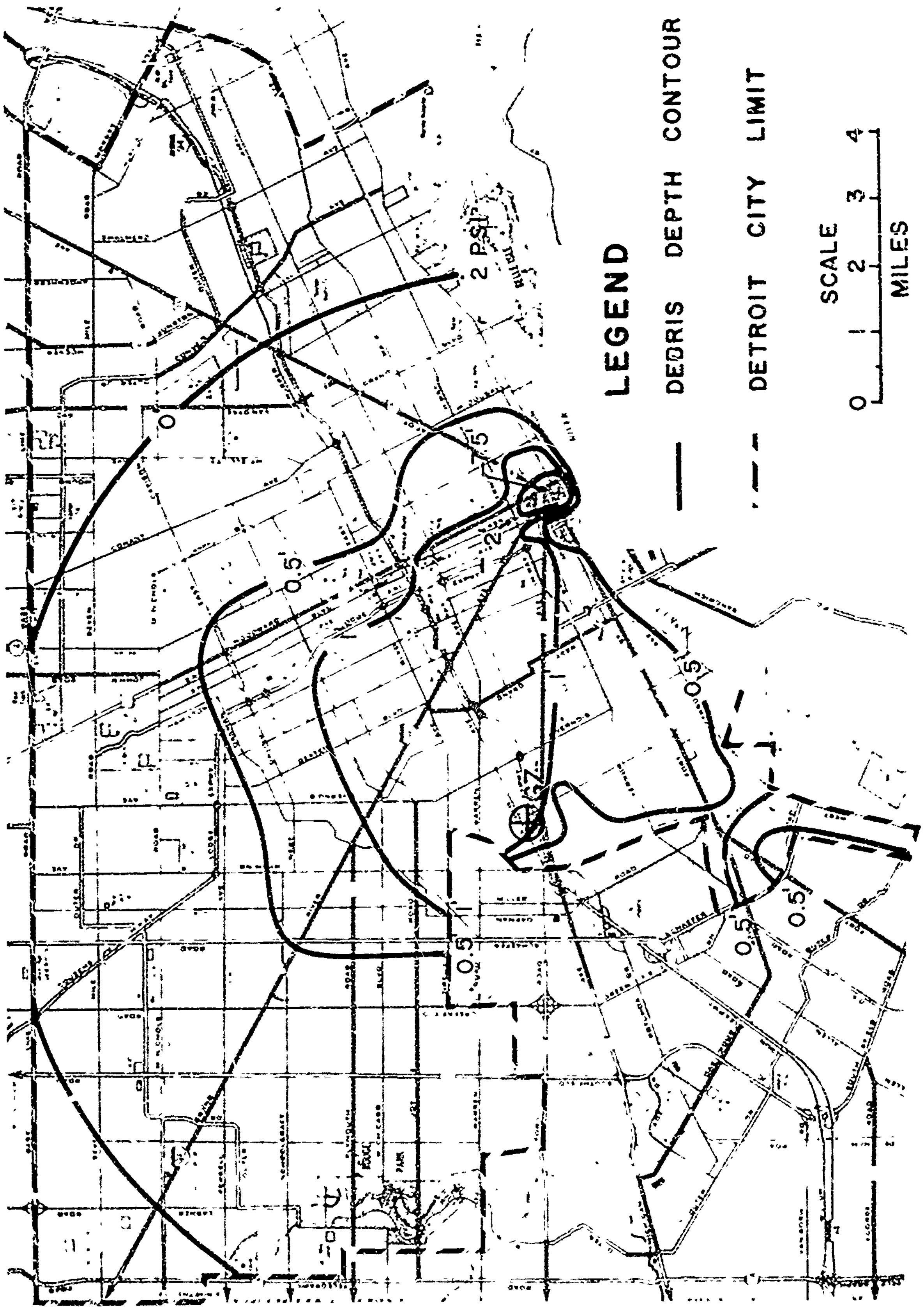

Fig. 12. Debris Depth Contour Map (Air blast only)

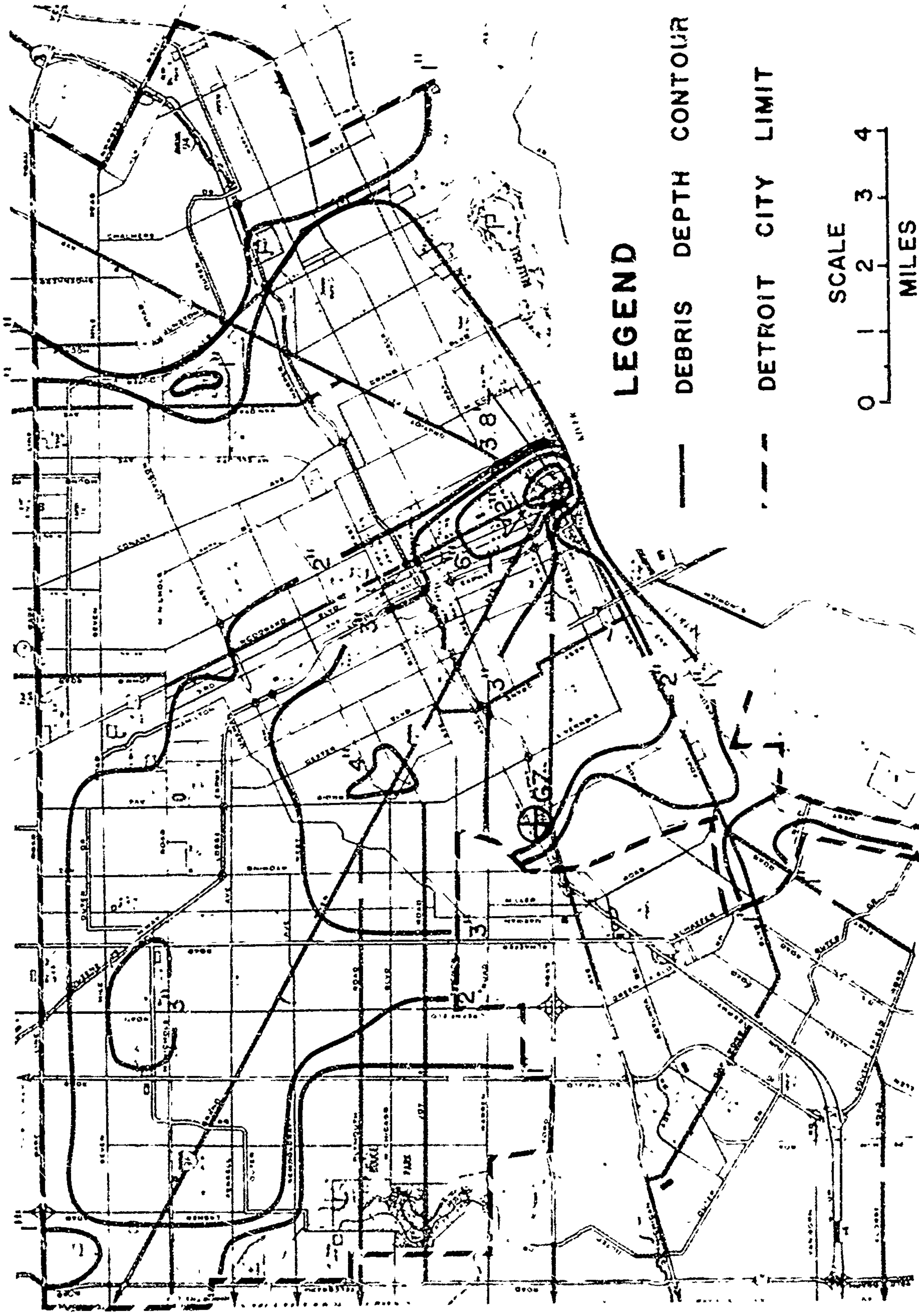

Fig. 13. Debris Depth Contour Map (Fire and air blast)

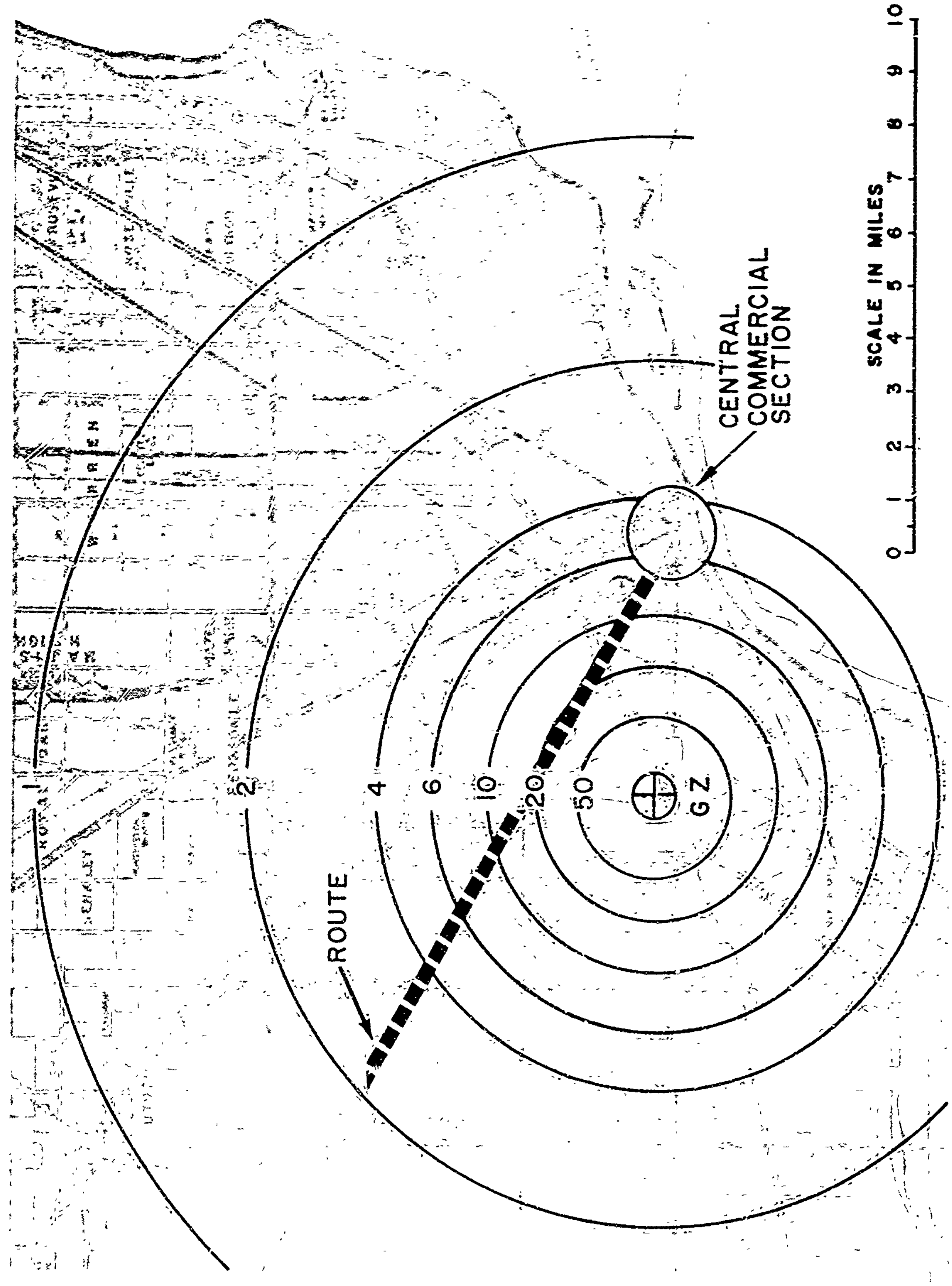

Fig. 14. Overpressure Isobars Over Detroit, Michigan, From a 5-Mt Surface Burst Attack

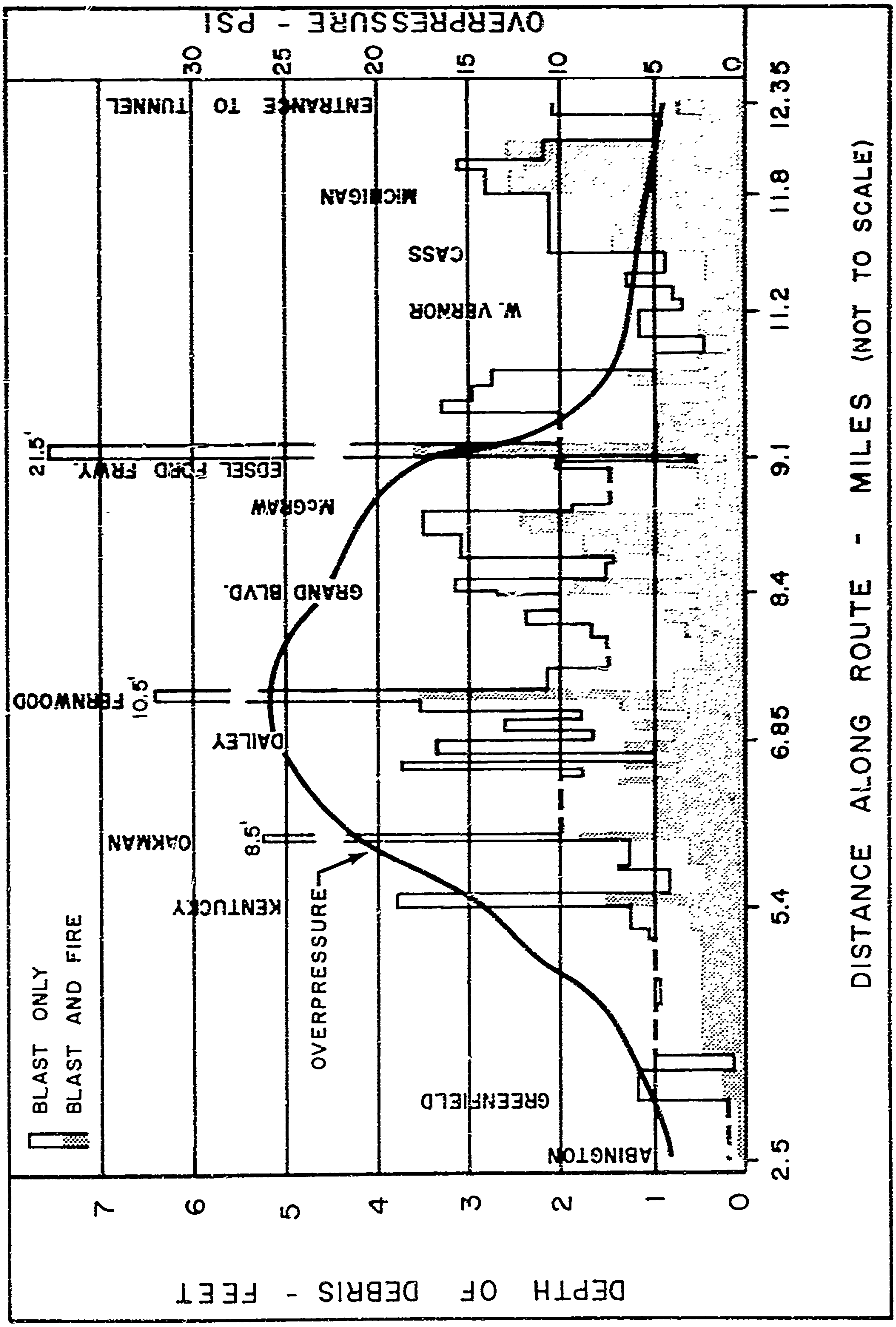

Fig. 15. Composite Profile of Debris Depths Along Route

The example problem provided an excellent illustration of the advantages that can be gained by selecting alternate routes detouring sections or areas containing greater debris depth.

RECOMMENDATIONS

To permit alternate routes to be evaluated and selected more quickly, and to permit the more rapid construction of depth contours with a higher degree of optimization and efficiency, it is recommended that the now cumbersome debris depth calculations be automated.

To improve the accuracy of these depth calculations, it is recommended that procedures for estimating the distribution of debris with respect to the donor building be substantially improved.

To provide more versatility (without losing accuracy), it is recommended that debris charts for a more complete range of weapon sizes and for some additional structure types frequently encountered (such as the hybrid structures containing shear walls acting compositely with a structural steel frame) be prepared. Even though damage data do not exist for these buildings, failure can be estimated theoretically, but with more work and a smaller degree of assurance as to accuracy.

To improve the predictions of debris depths in highly built-up city areas, it is recommended that the blast wave shielding afforded buildings by neighboring buildings be further studied.